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# MONTANA LARGE APERTURE SEISMIC ARRAY

Robert E. Matkins

Philco-Ford Corporation

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25 July 1973

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MONTANA LARGE APERTURE SEISMIC ARRAY

FINAL TECHNICAL REPORT, PROJECT VT 2708

CONTRACT F33657-72-C-0390

1 DECEMBER 1971 - 30 JUNE 1973

25 July 1973

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MONTANA LARGE APERTURE SEISMIC ARRAY

FINAL TECHNICAL REPORT

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13. ABSTRACT

The technical activity associated with the operation, maintenance, and improvement of the Montana Large Aperture Seismic Array (LASA) during the period 1 December 71 - 30 June 73 is related in this report. The short-period (SP) and long-period (LP) seismograph sensitivity performance statistics are indicated. The measured free period and mass position characteristics for the LP seismometer array are presented. Development of pseudo-random binary sequence (PRBS) calibration technique for the remote measurement of the amplitude, phase, and sensitivity characteristics of the LP seismograph over a broad band of frequencies is reported. Improvement to the PRBS calibrations recently developed for the SP seismograph is described. Statistics relating to the operation and maintenance of the array and data center equipment and land facilities support are provided.

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| | ROLE | WT | ROLE | WT | ROLE | WT |
| LASA - Large Aperture Seismic Array<br>Seismic Array<br>Seismic Observatory Operation<br>Seismic Measurement Channel Performance<br>Pseudo-random Binary Sequence Testing | | | | | | |

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## ABSTRACT

The continued operation, maintenance, and system improvement activities at the Montana Large Aperture Seismic Array during the period 1 Dec 70 through 30 Jun 73 are described. The array operations support provided to Seismic Array Analysis Center, the array monitoring and remote calibrations, the defective equipment detected, and the array communications outages are detailed. Performance measurements emphasizing the SP and LP seismograph long-term amplitude stability, frequency response, and natural frequency are discussed. The PDP-7 computer program to process the pseudo-random binary sequence calibrations is described. Reporting of near-regional event arrival times is announced. Equipment failures, failure rates, and actual mean time between failures for the ten array systems are given. Statistics relating to the operation and maintenance of the array and data center equipment and land facilities support are provided.



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## LIST OF FIGURES (CONCLUDED)

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## LIST OF TABLES (CONCLUDED)

## ACRONYMS

| | |
|---|---|
| AFSC | Air Force System Command |
| CTH | Central Terminal Housing |
| D/A | Digital to Analog |
| DCASD | Defense Contracts Administration Services District |
| EEO | Equal Employment Opportunity |
| IOT | Input Output Transfer |
| IRSPS | Integrated Research Seismic Processing System |
| LAO | LASA Subarray AO |
| LASA | Large Aperture Seismic Array |
| LASAPS | LASA Processing Systems |
| LDC | LASA Data Center |
| LOADUM | Load Upper Memory |
| LP | Long Period |
| MDC | Maintenance Display Console |
| MET | Meteorological |
| MOPS | Multiple On-line Processing System |
| MTBF | Mean Time Between Failures |
| NEIC | National Earthquake Information Center |
| NOAA/ERL | National Oceanic Atmospheric Administration |
| NORSAR | Norwegian Seismic Array |
| PRBS | Pseudo-random Binary Sequences |
| RPG | Random Pulse Generator |
| SAAC | Seismic Array Analysis Center |
| SDL | Seismic Data Laboratory |
| SEM | Subarray Electronics Module |

## ACRONYMS (CONCLUDED)

| | |
|---|---|
| SOU | Serial Output Unit |
| SP | Short Period |
| TELCO | Telephone Company |
| TFSO | Tonto Forest Seismological Observatory |
| VSC | VELA Seismological Center |
| WHV | Well Head Vault |
| WOSR | Work Order Search Retrieval |

## SECTION I

## INTRODUCTION

This report presents the accomplishments and administration of Contract Number F33657-72-C-0390. This contract between the Philco-Ford Corporation and AFSC Aeronautical Systems Division is for continued operation, research, and development of the Montana Large Aperture Seismic Array (LASA).

The LASA is part of the Vela Uniform Program which is sponsored by the Advanced Research Projects Agency (ARPA) of the Department of Defense. LASA is an experimental system consisting of many seismometers installed near Miles City, Montana, (Figure 1.1) used for the development of appropriate methods for the detection and identification of seismic events. Initially, the detection, location, and identification of seismic data were performed at the LASA Data Center (LDC) located at Billings, Montana. However, subsequent to implementation of the Integrated Seismic Research Signal Processing System (IRSPS), the array data is now transmitted to the Seismic Array Analysis Center (SAAC) in Alexandria, Va., for processing and analysis.

### 1.1 History

The LASA, installed in Eastern Montana during 1964 and 1965, is used for experiments in advanced seismological detection and discrimination. The initial installation, composed of 21 subarrays geometrically placed at a diameter of 200 kilometers with 525 short-period and 63 long-period seismometers, has evolved into the present array with the original 21 subarrays reduced to 346 short-period seismometers and 51 long-period seismometers.

Philco-Ford's participation in the Montana LASA began in 1964 by providing MIT Lincoln Laboratory with field engineering assistance. In June 1966, Philco-Ford assumed operational and maintenance responsibilities for MIT Lincoln Laboratory. On 1 May 1968, the project direction was transferred to the Electronics Systems Division, AFSC, with prime contracts to Philco-Ford through 30 November 1970.

On 1 December 1970, technical direction of the Montana LASA was assigned to the Vela Seismological Center (VSC). Under Projects V/T 1708 and V/T 2708 Philco-Ford continues the work of previous Montana LASA projects. This work basically involves the continued operation and maintenance of the array and data center systems, logistics and administrative support, data provision, and hardware evaluation and installation.

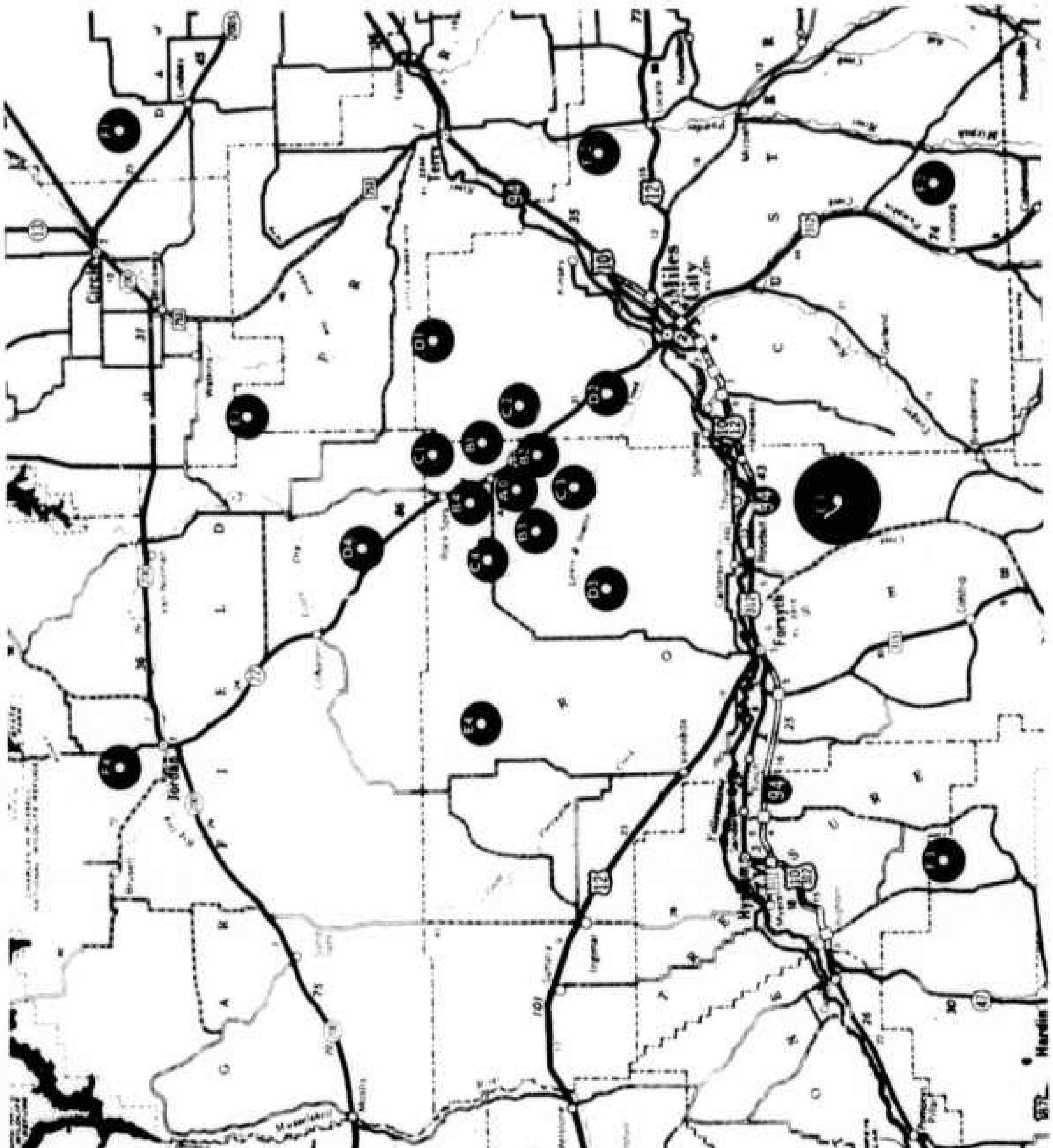



Figure 1.1 Montana LASA

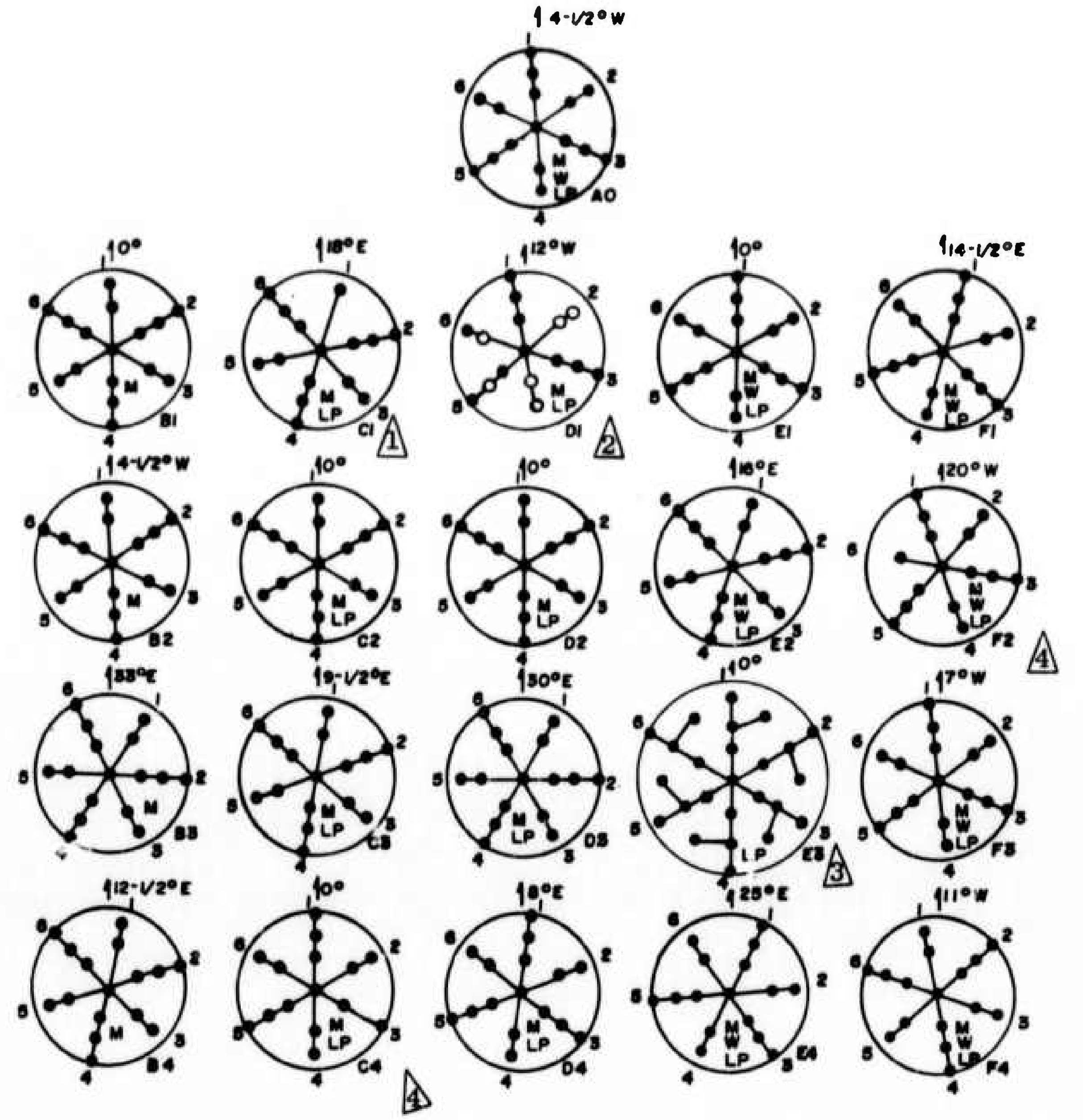
## 1.2 Description

The LASA with an overall diameter of 200 kilometers (124 miles) is composed of 21 subarrays arranged as shown in Figure 1.1. With the exception of subarray E3, which is 19 km in diameter, all subarrays are 7 km in diameter. Subarray E3 is configured with 25 short-period seismometers while others now have 16. All subarrays originally were designed with 25 seismometers each, however, programmed sensor removal has now lowered this number to 16 except at E3. The short-period seismometers are located along six radial cables which terminate in a central under-ground vault containing the Subarray Electronics Module (SEM). The subarrays also contain three-component long-period sensors, and weather sensors. Figure 1.2 shows the present configuration of each subarray.

The LDC controls the array operation by sending a command signal to each SEM at a rate of twenty times each second to cause sampling of the subarray signals. This command signal is suitably delayed at the LDC prior to transmission so that data from all SEMs will arrive at the LDC within predetermined time intervals.

The SEM responds to LDC timing system control signals with signal sampling, conversion, and transmission of all data to the LDC. Flexibility exists within the array in that the SEM can accomodate as many as 30 signal inputs; currently, signals from short and long-period seismometers, weather sensing equipment, and other measured parameters are telemetered. Signals from the 21 SEM's are transmitted to microwave junction points by open wire lines at a 19.2 kilobaud rate; from these points they are sent to the LDC by microwave radio facilities. At the LDC the data are processed and reformatted for transmission over a 50 kilobaud channel to SAAC. The LDC also contains the array timing and maintenance monitoring equipment. By means of telemetry commands, signal sources at the subarray are controlled to provide equipment calibrations and verify equipment performance.

The different LASA seismographs operating parameters and tolerances are identified in Tables I and II. Figure 1.3 shows the five different seismograph responses available.




Notes
1. SP Sensors removed from leg 1 because of access difficulties
2. 0 denotes near surface SP sensors
3. Expanded subarray, 18 km diameter
4. SP sensor inoperative and lost in cased hole

All degrees shown are orientations with respect to true north. The letters LP, M, and W denote long period seismic, microbarograph, and weather sensors installed at the center of the subarray. Microbarograph data was not available for transmission to SAAC after March 24, 1972.

Figure 1.2 LASA Subarray Configurations

TABLE I

LASA SEISMOGRAPH OPERATING PARAMETERS AND TOLERANCES

| CHANNEL IDENT. | OPERATING PARAMETERS AND TOLERANCES | | | | |
|---|---|---|---|---|---|
| | $T_s$ | $\lambda_s$ | $(MP_s)$ | $S_{chan}$ | Full Scale Within |
| SPZ | 1.0±0.1 | 0.7±0.1 | | 20±3mV/nm@1.0s | 609-823nm@1.0s |
| SPIZ | " | · | | " | " |
| SPTZ | 1.15 | 0.7 | | " | " |
| SPTN | 1.06 | " | | " | " |
| SPTE | 1.03 | " | | " | " |
| SPAZ | 1.0±0.1 | 0.7±0.1 | | 636±95mV/μm@1.0s | 19.2-25.9μm@1.0s |
| LPZ | 20.0±5% | 0.77 | 0±1.5mm | 350±50mV/μm@25s | 35.0-46.7μm@25s |
| LPH | " | " | " | " | " |
| LPAZ | " | " | " | 11±1.7mV/μm@25s | 1102-1505μm@25s |
| LPAH | " | " | " | " | " |
| LPWZ | " | " | " | 55±8.3mV/μm@25s | 221-300μm@25s |
| LPWH | " | " | " | " | " |

LEGEND: $T_s$ = Seismometer Free Period (Sec); $\lambda_s$ = Seismometer Damping

$(MP_s)$ = Seismometer Mass Position from Center

$S_{chan}$ = Channel Sensitivity

TABLE II

LASA SEISMOGRAPH CHANNEL IDENTIFICATION

| CHANNEL | MANUFACTURER/MODEL | SEISMIC AMPLIFIER MFGR/MODEL | FILTER MFGR/MODEL/TYPE |
|---|---|---|---|
| SPZ | GeoSpace/HS-10-1A | Texas Inst./RA-5 | 4 pole $\frac{1}{2}$dB ripple Chebyshev low pass, $f_c$=5.0 hertz, @10 hertz, -30dB. |
| SPAZ | GeoSpace/HS-10-1A | Texas Inst./RA-5 | |
| SPIZ | GeoSpace/HS-10-1B | Ithaco/6072-65 | " |
| SPTZ | Teledyne/TD-201D | Texas Inst./RA-5 | " |
| SPTN | Teledyne/TD-201D | Texas Inst./RA-5 | " |
| SPTE | Teledyne/TD-201D | Texas Inst./RA-5 | " |
| LPZ | Geotech/7505A | Texas Inst./Type II | Texas Inst./Type II/Response A. 24 dB/oct high-cut, centered at 65 sec. |
| LPH | Geotech/8700C | Texas Inst./Type II | |
| LPAZ | Geotech/7505A | Texas Inst./Type II | " |
| LPAH | Geotech/8700C | Texas Inst./Type II | " |
| LPWZ | Geotech/7507A | Texas Inst./Type II | Texas Inst./Type II/Response C. 12 dB/oct high-cut, centered at approx. 100 sec. |
| LPWH | Geotech/8700C | Texas Inst./Type II | |

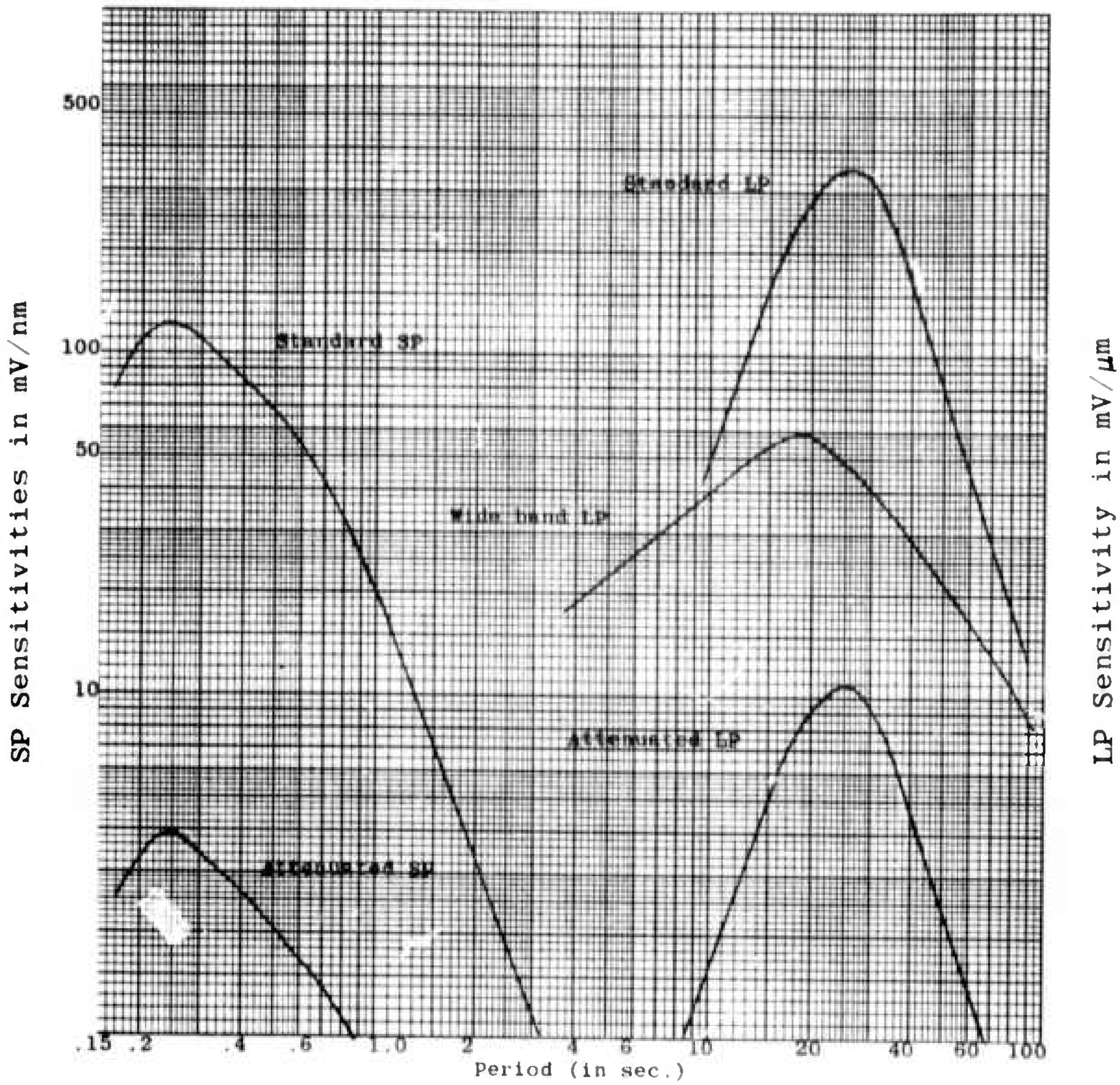



Figure 1.3 LASA Seismographs Response Curves

## SECTION II

## SUMMARY

The continued operation, maintenance, and system improvement activities at the Montana LASA during the period 1 Dec 70 through 30 Jun 73 are described. The array operation support provided to SAAC by the LDC computers totalled 95.1% of the period for on-line data transmission and 4.9% for back-up magnetic tape recording. Array monitoring and remote calibration procedures have been further developed to provide improved detection of array system malfunctions. Data communication circuits availability between the subarrays and the data center averaged 99.7%.

Performance measurements on the SP and LP systems have emphasized seismograph long-term amplitude stability, frequency response and natural frequency. The SP array sensitivity averaged 20.2 mV/nm at a one-second period and the amplitude stability showed improvement with a standard deviation of 1.2 compared with 1.7 mV/nm for the previous contract period. Individually the measured sensitivity of the SP instruments can be expected to be within 1 mV/nm of the mean sensitivity. For the LP array the sensitivity mean was 353.5 mV/$\mu$m at 25 seconds and the standard deviation 19.3 mV/$\mu$m. Development of a new technique utilizing pseudorandom binary sequences and the PDP-7 computer has allowed an increase in the number of seismograph frequency response measurements.

Natural frequency testing of the SP seismometers covering 68% of the array permits estimating that 90.8% of the instruments have natural frequencies within 1.0 $\pm$0.1 hertz; the SP array average is 1.035 hertz. The LP array seismometers natural frequencies averaged 19.93 sec/cycle with a 0.2% week-to-week variation of the array average. A weekly average of 2.5 remote adjustments maintained the 51-sensor array within the 20 $\pm$1 sec/cycle limit.

Use of the PDP-7 computer for array system calibration and monitoring continues to be main goal of the programming efforts. Development of programs to control and analyze the pseudorandom binary sequence calibrations offer a greater opportunity for more complete identification of the arrays seismographs as well as improving our ability to detect and diagnose defective instruments. The recent X-Y plotter installation should aid these efforts in the future.

Programming changes to the PDP-7 on-line system have increased the core memory available for patch-overlay

programs without reducing any of the processing capabilities. Detection of near-regional event arrivals has been initiated with reports distributed to SAAC and NOAA/ERL. Installation of the SP seismograph gain controls within the subarray central vault allows easier access to maintain amplitude variations within established limits throughout the entire year. Removal of the microbarograph array instruments is reported.

Maintenance activity and accomplishments are reported. Failure rate and actual MTBFs have been added to the failure data. A MTBF of 15.76 hours is indicated for the composite ten array systems. WHV facilities not in use are identified. The assistance provided to other agencies is indicated.

# SECTION III

# OPERATION

## 3.1 Introduction

Array operation is performed to provide data continuously from the array's sensing and data acquisition systems to the LDC, to provide digital data on-line from the LDC to the SAAC, to provide data recording in the event data transmission to SAAC is interrupted, and to insure the quality of the array's data is within established limits.

## 3.2 Data Center

The LASA Data Center (LDC) contains the equipment necessary to process the seismic array data either for transmission to SAAC or for recording locally. The operations which support the LASAPS and other data center systems include: (1) IBM 360/44 computer on-line to SAAC, (2) PDP-7 computer to record array data in back-up of the 360 computer and to perform array monitoring, automatic array systems calibrations, event detection, and off-line processing of array performance information, (3) maintenance display console for test and diagnosis of array equipment performance, (4) tape and film library for storage, handling, and shipment of array data recordings, (5) Develocorder for continuous recording of selected seismograph outputs and array quality control testing and analysis, and (6) telemetry link for continuous on-line data transmission of selected seismograph channels to MIT for data analysis.

### 3.2.1 SAAC/LDC Systems

One of the main goals of the data center's operation is insuring that a maximum amount of useful seismic data from the Montana array reaches SAAC over the real-time data link. During this 19-month contract period the Montana array was on-line with SAAC 95.15% of the time as compared with 89.15% for the previous contract period. During the 672.6 hours in which LASAPS data was not available at SAAC for use in the IRSPS operation, digital recordings of the LASA data were made by the PDP-7 computer (see para. 3.2.3). The three operational modes of the SAAC/LDC link which result in loss of Montana array data at SAAC are: (1) the SAAC computers are not available for LASAPS data acquisition, (2) the LDC 360 computer is not available for processing array data, and (3) the wideband communications channel between the SAAC and LDC is not in operation. Table III summarizes the SAAC/LDC system operation for each of the six reporting periods. Table IV provides a monthly breakdown of the same statistics for the final period.

TABLE III

FINAL SUMMARY SAAC/LDC SYSTEM OPERATING TIMES

| SYSTEM OPERATING MODE | Accumulated Operating Time, in hours, | | | | | | |
|---|---|---|---|---|---|---|---|
| | DEC 71 - FEB 72 | MAR 72 - MAY 72 | JUN 72 - AUG 72 | SEP 72 - NOV 72 | DEC 72 - FEB 73 | MAR 73 - JUN 73 | CONTRACT TOTALS |
| SAAC & LDC 360 On-Line | 2038.8 | 2082.6 | 2123.3 | 2097.5 | 2059.8 | 2797.4 | 13,199.4 |
| SAAC Off-Line, LDC 360 Up | | | | | | | |
| PDP-7 Recording | 58.0 | 93.2 | 42.8 | 65.3 | 44.7 | 70.3 | 374.3 |
| SAAC Up, LDC 360 Down, PDP-7 Recording | | | | | | | |
| Scheduled | 8.7 | 7.6 | 7.5 | 8.1 | 8.8 | 12.5 | 53.2 |
| Unscheduled | 17.6 | 0.6 | 1.4 | 0.4 | 28.8 | 43.4 | 92.2 |
| SAAC Up, Other Equipment Down, PDP-7 Recording | | | | | | | |
| Unscheduled | 60.9 | 24.0 | 33.0 | 12.7 | 17.9 | 4.4 | 152.9 |
| Totals (in hours) | 2184.0 | 2208.0 | 2208.0 | 2184.0 | 2160.0 | 2928.0 | 13,872.0 |

TABLE IV

SAAC/LDC SYSTEM OPERATING TIMES

March 73 - June 73

| SYSTEM OPERATING MODE | ACCUMULATED TIME, HOURS | | | | |
|---|---|---|---|---|---|
| | MAR. | APR. | MAY | JUNE | TOTALS |
| SAAC & LDC 360 On-Line | 726.7 | 658.0 | 711.7 | 701.0 | 2797.4 |
| SAAC Off-Line, LDC 360 Up | | | | | |
| PDP-7 Recording | 14.2 | 15.6 | 25.4 | 15.1 | 70.3 |
| SAAC Up, LDC 360 Down, PDP-7 Recording | | | | | |
| Scheduled | 2.6 | 2.3 | 4.6 | 3.0 | 12.5 |
| Unscheduled | 0.4 | 42.1 | 0.0 | 0.9 | 43.4 |
| SAAC Up, Other Equipment Down, PDP-7 Recording | | | | | |
| Unscheduled | 0.1 | 2.0 | 2.3 | 0.0 | 4.4 |
| Totals (in hours) | 744.0 | 720.0 | 744.0 | 720.0 | 2928.0 |

### 3.2.2 IBM/360 Computer

The LDC IBM/360 Model 44 Computer, the LASAPS data processor, operated 98.95% of the reporting period. This is an increase over the 97.9% reported for the previous contract. A summary of the computer utilization statistics are shown in Table V. On-line processing of array data accounted for 97.85% and downtime 2.15% of the total time available, i.e., 578 days x 24 hr/day or 13,872 hr. Table VI shows the utilization each month of the final period.

### 3.2.3 DEC PDP-7 Computer

The PDP-7 computer operations are presented in the Figure 3.1 where the capabilities developed for this system are indicated. The computer was fully operational for data center processing 97.53% of the contract of which on-line processing accounted for 77.02% and off-line 20.51%. The complete summary of computer utilization statistics is shown in Table VII and March through June statistics are covered in Table VIII.

The back-up operating mode of high-rate recording (Ref. 1) was required on 578 occasions covering an accumulated time period of 703.9 hours. During this operation 5296 magnetic tapes were recorded by the computer on 331 of the 578 days of this contract. Low-rate recordings totaling 5949 hours were also made. Both low-rate and high-rate recordings were retained at the LDC for at least 30 days of recycle time prior to reuse. Table IX details the monthly seismic data recording statistics.

### 3.2.4 Analog System

The LDC Analog System provides the capability of selecting, combining data and time signals, recording and/or retransmitting the analog output of any LASA data or seismograph channel. There are 96 digital-to-analog conversion channels and selection equipment for connecting any LASA channel to up to 16 different analog outputs simultaneously.

Two outputs are connected to Develocorders. One is operated to support data analysis work at SDL and the other to support array maintenance by providing a means to display selected sensor outputs during extended intervals of time. The SDL Develocorder operates 24 hr/day and each film record is scanned in the film viewer to determine the quality of film recording and to provide a log of occurrences affecting the film quality and usability.

Another analog system output provides the outputs of ten selected sensors for telemetering to MIT. The FM/FM equipment is composed of a transmitter with constant bandwidth

TABLE V

FINAL SUMMARY SYSTEM/360 MODEL 44 COMPUTER UTILIZATION

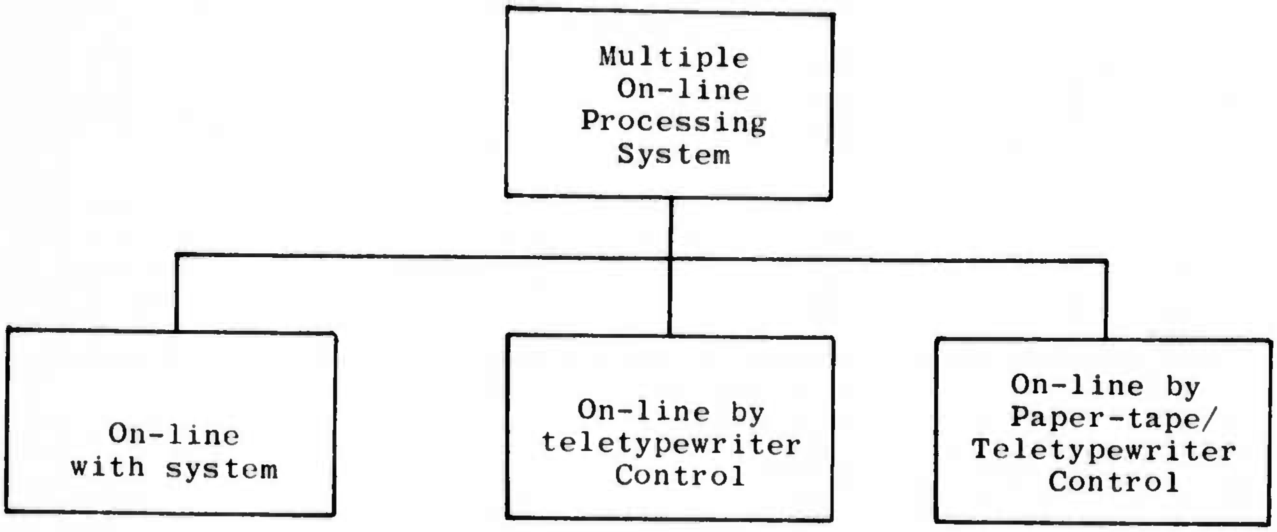
| OPERATING MODE | Accumulated Operating Time, in hours, | | | | | | |
|---|---|---|---|---|---|---|---|
| | DEC 71 - FEB 72 | MAR 72 - MAY 72 | JUN 72 - AUG 72 | SEP 72 - NOV 72 | DEC 72 - FEB 73 | MAR 73 - JUN 73 | CONTRACT TOTALS |
| On-line processing including: | | | | | | | |
| Fully operational with SAAC | 2038.8 | 2082.6 | 2123.3 | 2097.5 | 2059.8 | 2797.4 | 13,199.4 |
| Running at LASA only | 58.0 | 93.2 | 42.8 | 65.3 | 44.7 | 70.3 | 374.3 |
| Down-time operation including: | | | | | | | |
| Scheduled maintenance | 8.7 | 6.6 | 7.5 | 8.1 | 8.8 | 12.5 | 52.2 |
| Corrective maintenance | 13.5 | 0.0 | 0.0 | 0.4 | 28.6 | 21.9 | 64.4 |
| Training | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 |
| Shut down - 360 equipment | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 19.2 | 19.4 |
| Shut down - Other equipment | 60.9 | 24.0 | 33.0 | 11.9 | 17.0 | 4.4 | 151.2 |
| Program halt or loop | 4.1 | 0.6 | 1.4 | 0.8 | 0.9 | 2.3 | 10.1 |
| Idle time | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Totals | 2184.0 | 2208.0 | 2208.0 | 2184.0 | 2160.0 | 2928.0 | 13,872.0 |

TABLE VI

SYSTEM/360 MODEL 44 COMPUTER UTILIZATION

March 73 - June 73

| OPERATING MODE | ACCUMULATED TIME, HOURS | | | | |
|---|---|---|---|---|---|
| | MAR. | APR. | MAY | JUNE | TOTALS |
| On-line processing including: | | | | | |
| Fully operational with SAAC | 726.7 | 658.0 | 711.7 | 701.0 | 2797.4 |
| Running at LASA only | 14.2 | 15.6 | 25.4 | 15.1 | 70.3 |
| Down-time operation including: | | | | | |
| Scheduled maintenance | 2.6 | 2.3 | 4.6 | 3.0 | 12.5 |
| Corrective maintenance | 0.0 | 21.9 | 0.0 | 0.0 | 21.9 |
| Training | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Shut down - 360 equipment | 0.0 | 19.2 | 0.0 | 0.0 | 19.2 |
| Shut down - Other equipment | 0.1 | 2.0 | 2.3 | 0.0 | 4.4 |
| Program halt or loop | 0.4 | 1.0 | 0.0 | 0.9 | 2.3 |
| Idle time | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Totals | 744.0 | 720.0 | 744.0 | 720.0 | 2928.0 |




1. Weather
2. Event detection which includes beam forming
3. Monitor-provides Array telemetry/ alarm status

1. Hi-rate Record
2. Lo-rate Record
3. VLR Record
4. Weather
5. Display selected data through SOU
6. Monitor-provides array status, site deletions/ replacements
7. Programming changes and/or changing contents of selected core locations

1. TESP
2. TELP
3. MASPOS
4. FREECK
5. DC OFF
6. BATCK
7. DEVCAL
8. Card List
9. Tape List
10. Data-Playback
11. Standard Dev.
12. RPG ONE
13. FREQ
14. BEAM

Figure 3.1 PDP-7 Computer Operational Capabilities

TABLE VII

FINAL SUMMARY PDP-7 COMPUTER UTILIZATION

| OPERATING MODE | Accumulated Operating Time, in hours, | | | | | | |
|---|---|---|---|---|---|---|---|
| | DEC 71 - FEB 72 | MAR 72 - MAY 72 | JUN 72 - AUG 72 | SEP 72 - NOV 72 | DEC 72 - FEB 73 | MAR 73 - JUN 73 | CONTRACT TOTALS |
| On-Line Operation: | | | | | | | |
| Monitor | 46.3 | 489.6 | 701.6 | 559.0 | 730.6 | 751.7 | 3278.8 |
| VLR | 656.8 | 162.2 | 2.5 | 0.0 | 0.0 | 0.0 | 821.5 |
| HR Recording | 22.3 | 66.6 | 81.0 | 83.6 | 101.0 | 123.4 | 477.9 |
| LR Recording | 39.1 | 731.9 | 1011.0 | 715.3 | 929.0 | 1125.9 | 4552.2 |
| VLR & HR | 129.0 | 28.1 | 0.1 | 0.0 | 0.0 | 0.0 | 157.2 |
| VLR & LR | 1010.4 | 277.8 | 29.5 | 10.3 | 0.0 | 0.0 | 1328.0 |
| VLR & HR & LR | 0.2 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 |
| HR & LR | 0.3 | 36.5 | 8.9 | 7.4 | 5.6 | 9.6 | 68.3 |
| Off-Line Operation: | | | | | | | |
| Tape Duplicate/Verify | 19.4 | 6.4 | 0.0 | 0.0 | 0.0 | 9.0 | 34.8 |
| Data Analysis | 0.5 | 0.8 | 31.9 | 15.3 | 69.5 | 383.4 | 501.4 |
| Utility Operation | 35.6 | 46.1 | 39.3 | 420.0 | 156.1 | 113.9 | 811.0 |
| Program Development | 168.5 | 320.8 | 182.9 | 249.8 | 150.7 | 374.5 | 1447.2 |
| Diagnostic Testing | 13.1 | 5.3 | 18.6 | 10.0 | 2.3 | 0.4 | 49.7 |
| Training | 0.0 | 0.0 | 1.7 | 0.0 | 0.0 | 0.0 | 1.7 |
| Down Time Operation: | | | | | | | |
| Scheduled Maintenance | 1.0 | 2.0 | 3.6 | 3.5 | 0.0 | 1.6 | 11.7 |
| Unscheduled Maintenance | 25.7 | 9.3 | 47.6 | 89.8 | 11.7 | 15.3 | 199.4 |
| Shut Down/PDP-7 Inop. | 4.9 | 16.3 | 31.0 | 8.9 | 1.0 | 0.2 | 62.3 |
| Shut Down/Other Equip. | 0.0 | 0.7 | 0.5 | 6.4 | 0.0 | 13.9 | 21.5 |
| Program Halts | 10.6 | 3.0 | 16.3 | 4.4 | 2.5 | 0.8 | 37.6 |
| Idle | 0.3 | 4.3 | 0.0 | 0.3 | 0.0 | 4.4 | 9.3 |
| TOTALS | 2184.0 | 2208.0 | 2208.0 | 2184.0 | 2160.0 | 2928.0 | 13,872.0 |

TABLE VIII

PDP-7 COMPUTER UTILIZATION

March 73 - June 73

| OPERATING MODE | ACCUMULATED TIME, HOURS | | | | |
|---|---|---|---|---|---|
| | MAR. | APR. | MAY | JUNE | TOTALS |
| On-Line System Program Operation Including: | | | | | |
| Monitor & Weather | 191.9 | 195.2 | 183.4 | 181.2 | 751.7 |
| VLR | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| High Rate Recording Only | 17.7 | 58.7 | 28.8 | 18.2 | 123.4 |
| Low Rate Recording Only | 274.5 | 301.9 | 275.4 | 274.1 | 1125.9 |
| VLR & High Rate | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| VLR & Low Rate | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| VLR & High Rate & Low Rate | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| High Rate & Low Rate | 0.0 | 4.1 | 4.3 | 1.2 | 9.6 |
| Off-Line Program Operation Including: | | | | | |
| Tape Duplication & Verification | 0.0 | 0.0 | 6.0 | 3.0 | 9.0 |
| Data Analysis | 149.4 | 45.0 | 118.1 | 70.9 | 383.4 |
| Utility Operation | 13.9 | 30.2 | 36.9 | 32.9 | 113.9 |
| Program Development | 96.3 | 60.9 | 85.4 | 131.9 | 374.5 |
| Diagnostic Programs & Testing | 0.0 | 0.0 | 0.0 | 0.4 | 0.4 |
| Training | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Down Time Operation Including: | | | | | |
| Scheduled Maintenance | 0.0 | 0.8 | 0.8 | 0.0 | 1.6 |
| Unscheduled Maintenance | 0.0 | 9.0 | 4.6 | 1.7 | 15.3 |
| Shut Down - PDP-7 Inoperative | 0.0 | 0.0 | 0.2 | 0.0 | 0.2 |
| Shut Down - Other Equipment | 0.0 | 13.9 | 0.0 | 0.0 | 13.9 |
| Program Halts | 0.3 | 0.3 | 0.1 | 0.1 | 0.8 |
| Idle | 0.0 | 0.0 | 0.0 | 4.4 | 4.4 |
| Totals | 744.0 | 720.0 | 744.0 | 720.0 | 2928.0 |

TABLE IX

PDP-7 COMPUTER SEISMIC DATA RECORDING SUMMARY

| MONTH/YEAR | NO. HR REQUESTS | NO. HR TAPES | NO. HR HOURS | NO. LR HOURS | NO. VLR HOURS |
|---|---|---|---|---|---|
| 12/71 | 14 | 356 | 47.5 | | |
| 1/72 | 29 | 346 | 45.9 | 1050.0 | 1796.4 |
| 2/72 | 32 | 442 | 58.4 | | |
| 3/72 | 32 | 294 | 38.9 | | |
| 4/72 | 43 | 363 | 47.8 | 1046.8 | |
| 5/72 | 37 | 342 | 44.8 | | |
| 6/72 | 24 | 282 | 37.3 | | |
| 7/72 | 24 | 144 | 18.9 | 1049.4 | |
| 8/72 | 27 | 258 | 33.8 | | |
| 9/72 | 27 | 261 | 34.2 | | |
| 10/72 | 37 | 254 | 33.1 | | |
| 11/72 | 36 | 180 | 23.7 | 715.3 | |
| 12/72 | 46 | 558 | 74.3 | 316.9 | |
| 1/73 | 27 | 116 | 15.0 | 355.0 | |
| 2/73 | 18 | 130 | 17.3 | 262.7 | |
| 3/73 | 21 | 136 | 17.7 | 274.5 | |
| 4/73 | 32 | 448 | 62.8 | 306.0 | |
| 5/73 | 44 | 246 | 33.1 | 279.7 | |
| 6/73 | 28 | 140 | 19.4 | 275.3 | |
| TOTALS | 578 | 5296 | 703.9 | 5949.0 | 1796.4 |

(±62.5Hz) VCO's for multiplexing the signals onto one leased telephone circuit. Operation of this system is verified by periodic monitoring of the signals into the equipment and through telephone contact with Lincoln Laboratory personnel.

3.2.5 Tape/Film Library

The data center's library contains the PDP-7 computer magnetic tape recordings, the 360 computer disc recordings, and the Develocorder film recordings for reuse, reference, or storage prior to distribution. The libaray use statistics were:

5296 PDP-7 HR tapes retained for recycling,

4462 PDP-7 LR tapes retained for recycling,

681 PDP-7 seismic data tapes distributed, (SAAC-574, SDL-80, SMU-20,& MIT-7)

23 PDP-7 seismic data tapes retained for reference

The quality of the high-rate recordings are verified to be within a one percent error rate, i.e., less than 48 errors per tape. If this limit is exceeded twice, then the tape is cleaned prior to reuse. Then, if the limit is still exceeded, the tape is no longer used in the back-up, high-rate recording operation.

The tape library presently contains 3233 magnetic tapes. These tapes are 2400-ft, ½-inch tapes certified at 800 BPI. Approximately 2000 tapes are available for use in the seismic data recording cycle.

3.3 Array

Array operations functions performed include (1) monitoring of all array systems to detect equipment and data degradation, (2) testing of all array systems to measure equipment performance characteristics, (3) interfacing with telephone company personnel to determine communications equipment performance, and (4) processing of array maintenance and operation data to obtain statistics and information for efficient array management. These tasks are performed utilizing the PDP-7 computer, the maintenance display console, and the Develocorders.

3.3.1 Monitoring

Array monitoring refers to the sensing of performance of the operational equipment through the measurement of equipment characteristics on an essentially continuous basis. At the LDC continuous monitoring of the array systems is accomplished

using the built-in data monitors, viz. (1) the MDC alarm monitor panel, (2) the PDP-7 monitor program and (3) the 360 computer's on-line system. The MDC alarm monitor panel provides instantly both a visual and audible indication at the occurrence of either a data link failure between the LDC and a subarray or an alarm signal of subarray power and vault failures transmitted on telemetry word 31. The PDP-7 monitor program outputs each telemetry word 31 data change from any subarray and also prints out the duration of subarray data interruptions. The 360 computer's on-line system program periodically generates a variety of monitoring messages.

Operation and maintenance of the array equipment requires that the data be interrupted at various periods, during which time normal or reliable data may not be available to the LASA data user. The reasons established for data interruptions are: maintenance, either being performed or initiated; subarray equipment failure in which no maintenance has been initiated; telephone company(s) performing tests on the communication link not functioning; power outage at the subarray; or special data center testing. In the event any of these situations occur, a notation is made in the data interruption log relating to the data affected and the time period. For the case of short-period and long-period interruptions, SAAC is alerted via the System 360 typewriter.

The total durations of the data interruptions reported for the 19-month period were 1897.68h (0.65%), 1830.60h (0.78%), and 966.0h (0.87%) for the SP, LP, and meteorological data respectively. These figures included the TELCO outage with the array system outages. These may be compared with the previous contract percentages which were: SP(0.89%), LP(0.48%), and MET (0.98%). Table X reports the total outage durations of each system for each subarray. In summary these data show a decrease in the average hourly rate of SP subarray monthly outages from the previous contract, viz. 2.45 from 3.24, and increases for LP (3.00 from 2.35) and TELCO (2.30 from 2.08). A monthly breakdown of the data interruptions for March through June 1973 is given in Table XI.

### 3.3.2 Calibrations

Calibrations are performed from the data center to sense the performance of the operating array equipment through the periodic measurement and/or adjustment of one or more equipment characteristics.

#### 3.3.2.1 Seismograph Sinusoidal

Sinusoidal calibrations are performed daily for the short-period seismographs and weekly for the long-period systems. A set of telemetry remote controls (Ref. 2) connects the data center with each subarray and provides the means for

TABLE X

FINAL SUMMARY SUBARRAY DATA INTERRUPTION OUTAGES

December 1971 - June 1973

| DATA | TOTAL TIME DURATION OF DATA INTERRUPTIONS (h:m) | | | | | | |
|---|---|---|---|---|---|---|---|
| | AO | B1 | B2 | B3 | B4 | C1 | C2 |
| SP | 23:39 | 70:46 | 30:26 | 10:31 | 33:24 | 38:33 | 25:57 |
| LP | 25:47 | - | - | - | | 40:40 | 31:49 |
| μbaro | :07 | 0:0 | 0:0 | :37 | 0:0 | 0:0 | 0:0 |
| Meter | 18:57 | - | - | - | - | - | - |
| Telco | 30:33 | 16:19 | 12:46 | 8:44 | 17:58 | 20:04 | 26:36 |
| DATA | C3 | C4 | D1 | D2 | D3 | D4 | E1 |
| SP | 30:43 | 23:49 | 37:45 | 53:53 | 27:34 | 46:06 | 82:20 |
| LP | 31:28 | 27:34 | 40:58 | 130:33 | 48:21 | 48:14 | 84:27 |
| μbaro | :41 | :14 | :26 | 1:53 | :49 | :10 | 0:0 |
| Meter | - | - | - | - | - | - | 81:42 |
| Telco | 107:42 | 63:14 | 17:12 | 4.45 | 46:28 | 35:37 | 116:18 |
| DATA | E2 | E3 | E4 | F1 | F2 | F3 | F4 |
| SP | 31:25 | 57:27 | 52:58 | 19:57 | 57:12 | 207:12 | 17:43 |
| LP | 35:00 | 59:18 | 53:13 | 22:06 | 59:21 | 209:21 | 19:52 |
| μbaro | 0:0 | - | 0:0 | 3:03 | 0:0 | 0:0 | 0:0 |
| Meter | 30:45 | - | 51:26 | 19:17 | 56:32 | 206:02 | 17:03 |
| Telco | 13:05 | 56:40 | 54:09 | 34:36 | 8:10 | 82:44 | 144:41 |

TABLE XI

SUBARRAY DATA INTERRUPTION OUTAGES

| | | TOTAL TIME DURATION OF DATA INTERRUPTIONS (HOURS:MINUTES) | | | | |
|---|---|---|---|---|---|---|
| SUB ARRAY | DATA | MAR. | APR. | MAY | JUNE | TOTALS |
| AO | SP | :08 | :16 | -0- | 4:02 | 4:26 |
| | LP | :29 | :14 | -0- | 4 02 | 4:45 |
| | Meteor | -0- | -0- | -0- | -0- | -0- |
| | Telco | 3:55 | 1:11 | :53 | :40 | 6:39 |
| B1 | SP | :19 | :16 | -0- | 8:53 | 9:28 |
| | Telco | 3:39 | :13 | :53 | 4:07 | 8:52 |
| B2 | SP | :08 | :48 | 12:21 | -0- | 13:17 |
| | Telco | 5:27 | 1:05 | -0- | -0- | 6:32 |
| B3 | SP | :08 | :16 | -0- | -0- | :24 |
| | Telco | 3:37 | :13 | -0- | -0- | 3:50 |
| B4 | SP | 2:11 | 14:01 | :29 | 4:41 | 22:22 |
| | Telco | 4:09 | :13 | -0- | 1:38 | 6:00 |
| C1 | SP | 2:18 | :53 | -0- | -0- | 3:11 |
| | LP | 2:38 | :51 | -0- | -0- | 3:29 |
| | Telco | 4:09 | :13 | -0- | -0- | 4:22 |
| C2 | SP | :08 | :16 | -0- | :49 | 1:13 |
| | LP | :28 | :14 | -0- | :49 | 1:31 |
| | Telco | 5:27 | 1:05 | -0- | -0- | 6:32 |
| C3 | SP | 7:48 | :16 | 2:04 | 3:07 | 13:15 |
| | LP | 9:15 | :14 | 2:04 | 3:07 | 14:40 |
| | Telco | 4:01 | :13 | 2:25 | 86:50 | 93:29 |

SUBARRAY DATA INTERRUPTION OUTAGES (CONTINUED)

| | | TOTAL TIME DURATION OF DATA INTERRUPTIONS (HOURS:MINUTES) | | | | |
|---|---|---|---|---|---|---|
| SUB ARRAY | DATA | MAR. | APR. | MAY | JUNE | TOTALS |
| C4 | SP | :28 | :16 | -0- | :31 | 1:15 |
| | LP | :48 | :14 | -0- | :31 | 1:33 |
| | Telco | 3:37 | :43 | -0- | -0- | 4:20 |
| D1 | SP | :08 | 1:34 | -0- | :10 | 1:52 |
| | LP | :29 | 1:32 | -0- | :10 | 2:11 |
| | Telco | 4:00 | 4:29 | 3:31 | -0- | 12:00 |
| D2 | SP | :08 | :16 | :16 | -0- | :40 |
| | LP | :29 | :14 | :16 | -0- | :59 |
| | Telco | -0- | :13 | 1:37 | -0- | 1:50 |
| D3 | SP | :21 | :26 | 2:04 | -0- | 2:51 |
| | LP | :42 | :14 | 2:04 | -0- | 3:00 |
| | Telco | 4:00 | :13 | 2:00 | -0- | 6:13 |
| D4 | SP | 5:[illegible]4 | :16 | -0- | 1:03 | 6 33 |
| | LP | 5:35 | :14 | -0- | 1:03 | 6:52 |
| | Telco | 3:58 | :13 | 18:48 | -0- | 22:59 |
| F1 | SP | :13 | :16 | :29 | 1:07 | 2:05 |
| | LP | :33 | :14 | :29 | 1:07 | 2:23 |
| | Meteor | :05 | -0- | :29 | 1:07 | 1:43 |
| | Telco | 3:31 | :13 | -0- | -0- | 3:44 |
| E2 | SP | 1:59 | 1:41 | -0- | -0- | 3:40 |
| | LP | 2:19 | 1:39 | -0- | -0- | 3:58 |
| | Meteor | 1:51 | 1:25 | -0- | -0- | 3:16 |
| | Telco | -0- | :13 | 1:37 | -0- | 1:50 |

SUBARRAY DATA INTERRUPTION OUTAGES (CONCLUDED)

| | | TOTAL TIME DURATION OF DATA INTERRUPTIONS (HOURS:MINUTES) | | | | |
|---|---|---|---|---|---|---|
| SUB ARRAY | DATA | MAR. | APR. | MAY | JUNE | TOTALS |
| E3 | SP | :23 | :16 | 17:01 | 3:43 | 21:23 |
| | LP | :43 | :14 | 16:45 | 3:43 | 21:25 |
| | Telco | -0- | 1:57 | 38:12 | 1:23 | 41:32 |
| E4 | SP | :08 | 34:12 | -0- | :58 | 35:18 |
| | LP | :28 | 34:10 | -0- | :45 | 35:23 |
| | Meteor | -0- | 33:56 | -0- | :45 | 34:41 |
| | Telco | 3:42 | :53 | -0- | 5:28 | 10:03 |
| F1 | SP | :08 | :16 | 10:03 | :06 | 10:33 |
| | LP | :29 | :15 | 10:03 | :06 | 10:53 |
| | Meteor | -0- | -0- | 10:03 | :06 | 10:09 |
| | Telco | -0- | -0- | :37 | -0- | :37 |
| F2 | SP | :10 | :16 | -0- | 2:03 | 2:29 |
| | LP | :31 | :15 | -0- | 2:03 | 2:49 |
| | Meteor | :02 | -0- | -0- | 2:03 | 2:05 |
| | Telco | -0- | :13 | 1:37 | 1:03 | 2:53 |
| F3 | SP | :10 | 154:33 | 2:04 | 2:09 | 158:56 |
| | LP | :31 | 154:32 | 2:04 | 2:09 | 159:16 |
| | Meteor | :02 | 154:17 | 2:04 | 2:09 | 158:32 |
| | Telco | -0- | 1:50 | 23:06 | 1:42 | 26:38 |
| F4 | SP | :19 | :16 | -0- | -0- | :35 |
| | LP | :40 | :15 | -0- | -0- | :55 |
| | Meteor | :11 | -0- | -0- | -0- | :11 |
| | Telco | 3:36 | 5:31 | 5:21 | -0- | 14:28 |

determining the condition of the array equipment. The PDP-7 computer controls the application of the various telemetry command and calibration signals to the subarray(s), measures the signal responses, calculates the seismograph signal parameters, and outputs the data on punched-paper tape for off-line printout. Program TESP is used for the short-period seismographs; program TELP for the long-period seismographs (Ref. 2).

For the interest of the array data user, precise times in which the array seismographs are interrupted for sinusoidal calibrations are reported here. These times are readily available from the PDP-7 computers MOPS on-line monitor program output and are indicated in Tables XII and XIII for the SP and LP sensors respectively. For the short-period calibrations only one calibration time is shown in Table XII for each week; the daily times are available upon request from the LDC. The equivalent earth motion of the calibration input signals to the seismometers are also shown in the two tables. Equivalent earth motion is determined from SEM channel 30 measurements during the calibration times. SEM channel 30 monitors the output of the sinusoidal oscillators which generate the signals applied to the seismometer.

#### 3.3.2.2 Seismograph Frequency Response

Seismograph frequency response tests are performed with constant amplitude (~400 nmp-p) sinusoidal wave inputs over a range of frequencies applied from the CTH and outputs collected at the MDC. Program FREQ aids the MDC operator by automatically selecting the proper seismograph recording sequence over the subarray.

Frequency response testing was performed on sixteen subarrays on these dates: 28 Mar 72(B3), 7 Apr 72(E4), 19 Apr 72(C4), 16 May 72(AO), 21 May 72(F2), 9 Jun 72(F3), 30 Jun 72(F4), 12 Jul 72(E1), 17 Jul 72(E2), 10 Aug 72(D1), 5 Sep 72(C3), 8 Sep 72(C2), 6 Nov 72(B1), 24 Apr 73(B4), 9 May 73(B2), and 12 June 73(AO).

#### 3.3.2.3 Seismograph PRBS Responses

Broadband seismograph calibrations for both SP and LP using pseudo-random binary sequences (PRBS) commenced during this contract. Calibrations using the procedures and programs described in Section 5 are performed near the middle of each month. The time periods and subarrays involved for the tests performed to date are indicated in Table XIV.

#### 3.3.2.4 LP Seismometer Remote Adjustments

The remote measurement and adjustment of the long-period seismometer positioning is also performed weekly by

TABLE XII

SP ARRAY SINUSOIDAL CALIBRATIONS

| SUBARRAY | Short-Period Array Sinusoidal Calibration Signal Start Times and Amplitudes | | | | | | | | | | SUBARRAY |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Day 064 5 March 73 | | Day 071 12 March 73 | | Day 078 19 March 73 | | Day 085 26 March 73 | | Day 092 2 April 73 | | |
| | Start Time (GMT) | P-P Ampl. nm | Start Time (GMT) | P-P Ampl. nm | Start Time (GMT) | P-P Ampl. nm | Start Time (GMT) | P-P Ampl. nm | Start Time (GMT) | P-P Ampl. nm | |
| AO | 1632:53 | 407 | 1451:51 | 406 | 1501:24 | 406 | 1552:21 | 406 | 1542:53 | 405 | AO |
| B1 | 1633:23 | 400 | 1452:21 | 401 | 1501:54 | 401 | 1552:51 | 401 | 1543:23 | 400 | B1 |
| B2 | 1633:53 | 397 | 1452:51 | 397 | 1502:24 | 397 | 1553:21 | 397 | 1543:53 | 397 | B2 |
| B3 | 1634:23 | 418 | 1453:21 | 413 | 1502:54 | 417 | 1553:51 | 414 | 1544:23 | 416 | B3 |
| B4 | 1634:53 | 388 | 1453:51 | 400 | 1503:24 | 386 | 1554:21 | 401 | 1544:53 | 393 | B4 |
| C1 | 1635:23 | 421 | 1454:21 | 420 | 1503:54 | 420 | 1554:51 | 418 | 1545:23 | 418 | C1 |
| C2 | 1635:53 | 403 | 1454:51 | 403 | 1504:24 | 403 | 1555:21 | 403 | 1545:53 | 403 | C2 |
| C3 | 1636:23 | 420 | 1455:21 | 420 | 1504:54 | 420 | 1555:51 | 420 | 1546:23 | 420 | C3 |
| C4 | 1636:53 | 424 | 1455:51 | 424 | 1505:24 | 413 | 1556:21 | 420 | 1546:53 | 423 | C4 |
| D1 | 1637:23 | 405 | 1456:21 | 406 | 1505:54 | 406 | 1556:51 | 405 | 1547:23 | 403 | D1 |
| D2 | 1637:53 | 387 | 1456:51 | 387 | 1506:24 | 387 | 1557:21 | 388 | 1547:53 | 388 | D2 |
| D3 | 1638:23 | 375 | 1457:21 | 393 | 1506:54 | 392 | 1557:51 | 392 | 1548:23 | 393 | D3 |
| D4 | 1638:53 | 415 | 1457:51 | 414 | 1507:24 | 415 | 1558:21 | 413 | 1548:53 | 413 | D4 |
| E1 | 1639:23 | 415 | 1458:21 | 415 | 1507:54 | 415 | 1558:51 | 415 | 1549:23 | 416 | E1 |
| E2 | 1639:53 | 392 | 1458:51 | 393 | 1508:24 | 392 | 1559:21 | 393 | 1549:53 | 393 | E2 |
| E3 | 1640:23 | 387 | 1459:21 | 387 | 1508:54 | 387 | 1559:51 | 386 | 1550:23 | 387 | E3 |
| E4 | 1640:53 | 415 | 1459:51 | 417 | 1509:24 | 416 | 1600:21 | 415 | 1550:53 | 415 | E4 |
| F1 | 1641:23 | 402 | 1500:21 | 402 | 1509:54 | 400 | 1600:51 | 400 | 1551:23 | 400 | F1 |
| F2 | 1641:53 | 411 | 1500:51 | 411 | 1510:24 | 411 | 1601:21 | 411 | 1551:53 | 411 | F2 |
| F3 | 1642:23 | 413 | 1501:21 | 413 | 1510:54 | 413 | 1601:51 | 413 | 1552:23 | 413 | F3 |
| F4 | 1642:53 | 362 | 1501:51 | 362 | 1511:24 | 362 | 1602:21 | 362 | 1552:53 | 362 | F4 |

## SP ARRAY SINUSOIDAL CALIBRATIONS (CONTINUED)

| SUBARRAY | Short-Period Array Sinusoidal Calibration Signal Start Times and Amplitudes | | | | | | | | | | SUBARRAY |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Day 099<br>9 April 73 | | Day 106<br>16 April 73 | | Day 113<br>23 April 73 | | Day 120<br>30 April 73 | | Day 127<br>7 May 73 | | |
| | Start Time (GMT) | P-P Ampl. nm | Start Time (GMT) | P-P Ampl. nm | Start Time (GMT) | P-P Ampl. nm | Start Time (GMT) | P-P Ampl. nm | Start Time (GMT) | P-P Ampl. nm | |
| AO | 1734:26 | 405 | 1459:28 | 405 | 1518:47 | 406 | 1419:24 | 407 | 1641:06 | 405 | AO |
| B1 | 1734:56 | 401 | 1459:58 | 401 | 1519:17 | 400 | 1419:54 | 401 | 1641:36 | 401 | B1 |
| B2 | 1735:26 | 397 | 1500:28 | 397 | 1519:47 | 396 | 1420:24 | 396 | 1642:06 | 396 | B2 |
| B3 | 1735:56 | 417 | 1500:58 | 411 | 1520:17 | 415 | 1420:54 | 414 | 1642:36 | 410 | B3 |
| B4 | 1736:26 | 392 | 1501:28 | 404 | 1520:47 | 392 | 1421:24 | 393 | 1643:06 | 428 | B4 |
| C1 | 1736:56 | 418 | 1501:58 | 407 | 1521:17 | 418 | 1421:54 | 418 | 1643:36 | 417 | C1 |
| C2 | 1737:26 | 403 | 1502:28 | 403 | 1521:47 | 403 | 1422:24 | 403 | 1644:06 | 403 | C2 |
| C3 | 1737:56 | 420 | 1502:58 | 420 | 1522:17 | 420 | 1422:54 | 418 | 1644:36 | 418 | C3 |
| C4 | 1738:26 | 424 | 1503:28 | 425 | 1522:47 | 424 | 1423:24 | 424 | 1645:06 | 425 | C4 |
| D1 | 1738:56 | 410 | 1503:58 | 408 | 1523:17 | 408 | 1423:54 | 410 | 1645:36 | - | D1 |
| D2 | 1739:26 | 388 | 1504:28 | 388 | 1523:47 | 388 | 1424:24 | 388 | 1646:06 | 388 | D2 |
| D3 | 1739:56 | 385 | 1504:58 | 385 | 1524:17 | 384 | 1424:54 | 383 | 1646:36 | 384 | D3 |
| D4 | 1740:26 | 414 | 1505:28 | 412 | 1524:47 | 413 | 1425:24 | 412 | 1647:06 | 408 | D4 |
| E1 | 1740:56 | 415 | 1505:58 | 416 | 1525:17 | 416 | 1425:54 | 416 | 1647:36 | 406 | E1 |
| E2 | 1741:26 | 393 | 1506:28 | 393 | 1525:47 | 394 | 1426:24 | 402 | 1648:06 | 397 | E2 |
| E3 | 1741:56 | 388 | 1506:58 | 387 | 1526:17 | 388 | 1426:54 | 387 | 1648:36 | 369 | E3 |
| E4 | 1742:26 | 417 | 1507:28 | 417 | 1526:47 | 416 | 1427:24 | 416 | 1649:06 | 416 | E4 |
| F1 | 1742:56 | 402 | 1507:58 | 400 | 1527:17 | 400 | 1427:54 | 401 | 1649:36 | 398 | F1 |
| F2 | 1743:26 | 411 | 1508:28 | 411 | 1527:47 | 411 | 1428:24 | 411 | 1650:06 | 411 | F2 |
| F3 | 1743:56 | 413 | 1508:58 | 413 | - | - | 1428:54 | 408 | 1650:36 | 407 | F3 |
| F4 | 1744:26 | 362 | 1509:28 | 362 | 1528:47 | 362 | 1429:24 | 367 | 1651:06 | 362 | F4 |

SP ARRAY SINUSOIDAL CALIBRATIONS (CONTINUED)

| SUBARRAY | Short-Period Array Sinusoidal Calibration Signal Start Times and Amplitudes | | | | | | | | | | SUBARRAY |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Day 134 14 May 73 | | Day 141 21 May 73 | | Day 148 28 May 73 | | Day 155 4 June 73 | | Day 162 11 June 73 | | |
| | Start Time (GMT) | P-P Ampl. nm | Start Time (GMT) | P-P Ampl. nm | Start Time (GMT) | P-P Ampl. nm | Start Time (GMT) | P-P Ampl. nm | Start Time (GMT) | P-P Ampl. nm | |
| AO | 2210:24 | 402 | 1524:07 | 401 | 1430:09 | 401 | 1413:07 | 402 | 2102:50 | 398 | AO |
| B1 | 2210:54 | 401 | 1524:37 | 401 | 1430:39 | 400 | 1413:37 | 401 | 2103:20 | 401 | B1 |
| B2 | 2211:24 | 397 | 1525:07 | 396 | 1431:09 | 397 | 1414:07 | 396 | 2103:50 | 396 | B2 |
| B3 | 2211:54 | 411 | 1525:37 | 410 | 1431:39 | 406 | 1414:37 | 404 | 2104:20 | 403 | B3 |
| B4 | 2212:24 | 433 | 1526:07 | 436 | 1432:09 | 438 | 1415:07 | 437 | 2104:50 | 444 | B4 |
| C1 | 2212:54 | 415 | 1526:37 | 414 | 1432:39 | 414 | 1415:37 | 414 | 2105:20 | 412 | C1 |
| C2 | 2213:24 | 402 | 1527:07 | 403 | 1433:09 | 403 | 1416:07 | 402 | 2105:50 | 402 | C2 |
| C3 | 2213:54 | 418 | 1527:37 | 418 | 1433:39 | 418 | 1416:37 | 418 | 2106:20 | 417 | C3 |
| C4 | 2214:24 | 425 | 1528:07 | 427 | 1434:09 | 426 | 1417:07 | 425 | 2106:50 | 427 | C4 |
| D1 | 2214:54 | 406 | 1528:37 | 407 | 1434:39 | 407 | 1417:37 | 407 | 2107:20 | 404 | D1 |
| D2 | 2215:24 | 390 | 1529:07 | 391 | 1435:09 | 390 | 1418:07 | 390 | 2107:50 | 391 | D2 |
| D3 | 2215:54 | 366 | 1529:37 | 367 | 1435:39 | 367 | 1418:37 | 367 | 2108:20 | 395 | D3 |
| D4 | 2216:24 | 406 | 1530:07 | 405 | 1436:09 | 404 | 1419:07 | 405 | 2108:50 | 400 | D4 |
| E1 | 2216:54 | 407 | 1530:37 | 408 | 1436:39 | 410 | 1419:37 | 407 | 2109:20 | 408 | E1 |
| E2 | 2217:24 | 397 | 1531:07 | 398 | 1437:09 | 398 | 1420:07 | 398 | 2109:50 | 401 | E2 |
| E3 | 2217:54 | 382 | 1531:37 | 380 | 1437:39 | 380 | 1420:37 | 380 | 2110:20 | 375 | E3 |
| E4 | 2218:24 | 415 | 1532:07 | 415 | 1438:09 | 415 | 1421:07 | 415 | 2110:50 | 413 | E4 |
| F1 | 2218:54 | 397 | 1532:37 | 398 | 1438:39 | 396 | 1421:37 | 396 | 2111:20 | 395 | F1 |
| F2 | 2219:24 | 411 | 1533:07 | 411 | 1439:09 | 411 | 1422:07 | 411 | 2111:50 | 411 | F2 |
| F3 | 2219:54 | 406 | 1533:37 | 398 | 1439:39 | 395 | 1422:37 | 392 | 2112:20 | 394 | F3 |
| F4 | 2220:24 | 363 | 1534:07 | 363 | 1440:09 | 363 | 1423:07 | 363 | 2112:50 | 364 | F4 |

SP ARRAY SINUSOIDAL CALIBRATIONS (CONCLUDED)

| SUBARRAY | Short-Period Array Sinusoidal Calibration Signal Start Times and Amplitudes | | | | SUBARRAY |
|---|---|---|---|---|---|
| | Day 169 18 June 73 | | Day 176 25 June 73 | | |
| | Start Time (GMT) | P-P Ampl. nm | Start Time (GMT) | P-P Ampl. nm | |
| AO | 2116:31 | 398 | 1520:15 | 397 | AO |
| B1 | 2117:01 | 401 | 1520:45 | 401 | B1 |
| B2 | 2117:31 | 396 | 1521:15 | 396 | B2 |
| B3 | 2118:01 | 405 | 1521:45 | 398 | B3 |
| B4 | 2118:31 | 436 | 1522:15 | 379 | B4 |
| C1 | 2119:01 | 413 | 1522:45 | 412 | C1 |
| C2 | 2119:31 | 402 | 1523:15 | 402 | C2 |
| C3 | 2120:01 | - | 1523:45 | 417 | C3 |
| C4 | 2120:31 | 427 | 1524:15 | 426 | C4 |
| D1 | 2121:01 | 405 | 1524:45 | 404 | D1 |
| D2 | 2121:31 | 391 | 1525:15 | 391 | D2 |
| D3 | 2122:01 | 394 | 1525:45 | 394 | D3 |
| D4 | 2122:31 | 403 | 1526:15 | 397 | D4 |
| E1 | 2123:01 | 410 | 1526:45 | 410 | E1 |
| E2 | 2123:31 | 400 | 1527:15 | 401 | E2 |
| E3 | 2124:01 | 375 | 1527:45 | 370 | E3 |
| E4 | 2124:31 | 412 | 1528:15 | 410 | E4 |
| F1 | 2125:01 | 397 | 1528:45 | 394 | F1 |
| F2 | 2125:31 | 411 | 1529:15 | 411 | F2 |
| F3 | 2126:01 | 392 | 1529:45 | 387 | F3 |
| F4 | 2126:31 | 363 | 1530:15 | 363 | F4 |

TABLE XIII

LP ARRAY SINUSOIDAL CALIBRATIONS

| SUBARRAY | Long-Period Array Sinusoidal Calibration Signal Times and Input Amplitudes | | | | | | | | | SUBARRAY |
|---|---|---|---|---|---|---|---|---|---|---|
| | Day 064: 5 Mar. 73 | | | Day 071: 12 Mar. 73 | | | Day 078: 19 Mar. 73 | | | |
| | Start Time (GMT) | Stop Time (GMT) | Input Ampl. μm P-P | Start Time (GMT) | Stop Time (GMT) | Input Ampl. μm P-P | Start Time (GMT) | Stop Time (GMT) | Input Ampl. μm P-P | |
| AO | 1455:20 | 1459:07 | 20.0 | 1648:54 | 1652:39 | 20.0 | 1520:04 | 1523:50 | 20.0 | AO |
| C1 | 1455:20 | 1459:07 | 19.1 | 1648:54 | 1652:39 | 19.0 | 1520:04 | 1523:50 | 19.2 | C1 |
| C2 | 1505 42 | 1509:33 | 108 | 1659:14 | 1703:03 | 108 | 1530:25 | 1533:59 | 108 | C2 |
| C3 | 1505:42 | 1509:33 | 20.4 | 1659:14 | 1703:03 | 20.2 | 1530:25 | 1533:59 | 20.4 | C3 |
| C4 | 1516:13 | 1519:51 | 20.7 | 1709:43 | 1713:10 | 20.7 | 1540:39 | 1544:17 | 20.7 | C4 |
| D1 | 1516:13 | 1519:51 | 20.4 | 1709:43 | 1713:10 | 20.5 | 1540:39 | 1544:17 | 20.4 | D1 |
| D2 | 1526:18 | 1530:01 | 20.3 | 1719:37 | 1723:15 | 20.3 | 1550:44 | 1554:32 | 20.3 | D2 |
| D3 | 1526:18 | 1530:01 | 19.0 | 1719:37 | 1723:15 | 19.0 | 1550:44 | 1554:32 | 19.0 | D3 |
| D4 | 1536:39 | 1540:10 | 20.8 | 1729:53 | 1733:33 | 20.8 | 1601:10 | 1604:46 | 20.8 | D4 |
| E1 | 1536.39 | 1540:10 | 19.7 | 1729:53 | 1733:33 | 19.7 | 1601:10 | 1604:46 | 19.7 | E1 |
| E2 | 1546:54 | 1550:27 | 20.7 | 1740:17 | 1743:52 | 20.7 | 1611.30 | 1615:06 | 20.7 | E2 |
| E3 | 1546:54 | 1550:27 | 19.6 | 1740:17 | 1743:52 | 19.7 | 1611:30 | 1615:06 | 19.7 | E3 |
| E4 | 1556:52 | 1600:29 | 20.5 | 1750:18 | 1753:52 | 20.5 | 1621:32 | 1625:03 | 20.5 | E4 |
| F1 | 1556:52 | 1600:29 | 20.2 | 1750:18 | 1753:52 | 20.2 | 1621:32 | 1625:03 | 20.2 | F1 |
| F2 | 1606:58 | 1610:43 | 20.6 | 1800:21 | 1803:58 | 20.6 | 1631:32 | 1635:01 | 20.6 | F2 |
| F3 | 1606:58 | 1610:43 | 19.9 | 1800:21 | 1803:58 | 19.9 | 1631:32 | 1635:01 | 19.9 | F3 |
| F4 | 1617:22 | 1621:04 | 19.9 | 1810:37 | 1814:14 | 19.9 | 1641:40 | 1645:23 | 19.9 | F4 |

LP ARRAY SINUSOIDAL CALIBRATIONS (CONTINUED)

| SUBARRAY | Long-Period Array Sinusoidal Calibration Signal Times and Input Amplitudes | | | | | | | | | SUBARRAY |
|---|---|---|---|---|---|---|---|---|---|---|
| | Day 085: 26 Mar. 73 | | | Day 092: 2 Apr. 73 | | | Day 099: 9 Apr. 73 | | | |
| | Start Time (GMT) | Stop Time (GMT) | Input Ampl. μm P-P | Start Time (GMT) | Stop Time (GMT) | Input Ampl. μm P-P | Start Time (GMT) | Stop Time (GMT) | Input Ampl. μm P-P | |
| AO | 1613:00 | 1616:49 | 20.0 | 1601:52 | 1605:29 | 20.0 | 1749:16 | 1752:52 | 20.0 | AO |
| C1 | 1613:00 | 1616:49 | 19.1 | 1601:52 | 1605:29 | 19.1 | 1749:16 | 1752:52 | 19.2 | C1 |
| C2 | 1623:24 | 1627:16 | 108 | 1612:04 | 1615:45 | 108 | 1759:27 | 1803:03 | 108 | C2 |
| C3 | 1623:24 | 1627:16 | 20.4 | 1612:04 | 1615:45 | 20.4 | 1759:27 | 1803:03 | 20.3 | C3 |
| C4 | 1633:56 | 1637:39 | 20.7 | 1622:25 | 1625:50 | 20.7 | 1809:43 | 1813:25 | 20.7 | C4 |
| D1 | 1633:56 | 1637:39 | 20.4 | 1622:25 | 1625:50 | 20.5 | 1809:43 | 1813:25 | 21.0 | D1 |
| D2 | 1644:07 | 1647:50 | 20.3 | 1632:17 | 1636:02 | 20.3 | 1819:52 | 1823:25 | 20.3 | D2 |
| D3 | 1644:07 | 1647:50 | 18.9 | 1632:17 | 1636:02 | 18.9 | 1819:52 | 1823:25 | 18.9 | D3 |
| D4 | 1654:28 | 1658:01 | 20.8 | 1642:40 | 1646:32 | 20.8 | 1830:03 | 1833:57 | 20.8 | D4 |
| E1 | 1654:28 | 1658:01 | 19.7 | 1642:40 | 1646:32 | 19.7 | 1830:03 | 1833:57 | 19.7 | E1 |
| E2 | 1704:44 | 1708:25 | 20.7 | 1653:15 | 1656:59 | 20.7 | 1840:40 | 1844:03 | 20.7 | E2 |
| E3 | 1704:44 | 1708:25 | 19.7 | 1653:15 | 1656:59 | 19.7 | 1840:40 | 1844:03 | 19.7 | E3 |
| E4 | 1714:51 | 1718:17 | 20.6 | 1703:25 | 1707:07 | 20.5 | 1850:28 | 1853:57 | 20.5 | E4 |
| F1 | 1714:51 | 1718:17 | 20.2 | 1703:25 | 1707:07 | 20.2 | 1850:28 | 1853:57 | 20.2 | F1 |
| F2 | 1724:47 | 1728:27 | 20.6 | 1901:10 | 1904:45 | 20.6 | 1900:26 | 1904:09 | 20.6 | F2 |
| F3 | 1724:47 | 1728:27 | 19.9 | 1920:55 | 1924:27 | 19.9 | 1900:26 | 1904:09 | 19.9 | F3 |
| F4 | 1735:06 | 1738:39 | 19.7 | 1938:33 | 1942:15 | 19.9 | 1910:48 | 1914:16 | 19.9 | F4 |

LP ARRAY SINUSOIDAL CALIBRATIONS (CONTINUED)

| SUBARRAY | Long-Period Array Sinusoidal Calibration Signal Times and Input Amplitudes | | | | | | | | | SUBARRAY |
|---|---|---|---|---|---|---|---|---|---|---|
| | Day 106: 16 Apr. 73 | | | Day 113: 23 Apr. 73 | | | Day 120: 30 Apr. 73 | | | |
| | Start Time (GMT) | Stop Time (GMT) | Input Ampl. μm P-P | Start Time (GMT) | Stop Time (GMT) | Input Ampl. μm P-P | Start Time (GMT) | Stop Time (GMT) | Input Ampl. μm P-P | |
| AO | 1513:53 | 1517:20 | 20.0 | 1543:29 | 1547:15 | 20.0 | 1438:33 | 1442:00 | 20.0 | AO |
| C1 | 1513:53 | 1517:20 | 19.2 | 1543:29 | 1547:15 | 19.1 | 1438:33 | 1442:00 | 19.1 | C1 |
| C2 | 1523:55 | 1527:27 | 108 | 1553:50 | 1557:29 | 108 | 1448:36 | 1452:12 | 108 | C2 |
| C3 | 1523:55 | 1527:27 | 20.4 | 1553:50 | 1557:29 | 20.4 | 1448:36 | 1452:12 | 20.4 | C3 |
| C4 | 1534:06 | 1537:38 | 20.7 | 1604:09 | 1607:33 | 20.7 | 1458:53 | 1502:17 | 20.7 | C4 |
| D1 | 1534:06 | 1537:38 | 21.0 | 1604:09 | 1607:33 | 20.4 | 1458:53 | 1502:17 | 20.5 | D1 |
| D2 | 1544:05 | 1547:54 | 20.3 | 1614:01 | 1617:42 | 20.3 | 1508:45 | 1512:23 | 20.3 | D2 |
| D3 | 1544:05 | 1547:54 | 18.9 | 1614:01 | 1617:42 | 18.9 | 1508:45 | 1512:23 | 18.9 | D3 |
| D4 | 1554:31 | 1558:23 | 20.8 | 1624:20 | 1628:09 | 20.8 | 1519:01 | 1522:52 | 20.8 | D4 |
| E1 | 1554:31 | 1558:23 | 19.7 | 1624:20 | 1628:09 | 19.8 | 1519:01 | 1522:52 | 19.7 | E1 |
| E2 | 1605:06 | 1608:51 | 20.7 | 1634:53 | 1638:29 | 20.7 | 1529:36 | 1533:01 | 20.7 | E2 |
| E3 | 1605:06 | 1608:51 | 19.7 | 1634:53 | 1638:29 | 19.7 | 1529:36 | 1533:01 | 19.6 | E3 |
| E4 | 1615:16 | 1618:40 | 20.5 | 1644:55 | 1648:40 | 20.6 | 1539:28 | 1542:58 | 20.5 | E4 |
| F1 | 1615:16 | 1618:40 | 20.2 | 1644:55 | 1648:40 | 20.1 | 1539:28 | 1542:58 | 20.1 | F1 |
| F2 | 1625:09 | 1629:01 | 20.6 | 1655:10 | 1658:43 | 20.6 | 1549:28 | 1553:21 | 20.6 | F2 |
| F3 | 1625:09 | 1629:01 | 19.9 | - | - | - | 1549:29 | 1553:21 | 21.0 | F3 |
| F4 | 1635:39 | 1639:18 | 19.9 | 1705:22 | 1708:49 | 19.9 | 1600:01 | 1603:33 | 19.9 | F4 |

LP ARRAY SINUSOIDAL CALIBRATIONS (CONTINUED)

| SUBARRAY | Long-Period Array Sinusoidal Calibration Signal Times and Input Amplitudes | | | | | | | | | SUBARRAY |
|---|---|---|---|---|---|---|---|---|---|---|
| | Day 128: 8 May 73 | | | Day 134: 14 May 73 | | | Day 141: 21 May 73 | | | |
| | Start Time (GMT) | Stop Time (GMT) | Input Ampl. μm P-P | Start Time (GMT) | Stop Time (GMT) | Input Ampl. μm P-P | Start Time (GMT) | Stop Time (GMT) | Input Ampl. μm P-P | |
| AO | 1620:14 | 1623:48 | 20.0 | 2026:02 | 2029:52 | 20.0 | 1537:13 | 1540:40 | 20.0 | AO |
| C1 | 1620:14 | 1623:48 | 19.1 | 2026.02 | 2029:52 | 19.1 | 1537:13 | 1540:40 | 19.2 | C1 |
| C2 | 1630:24 | 1634:11 | 108 | 2036:27 | 2040:17 | 108 | 1547:15 | 1550:55 | 108 | C2 |
| C3 | 1630:24 | 1634:11 | 20.4 | 2036:27 | 2040:17 | 20.4 | 1547:15 | 1550:55 | 20.4 | C3 |
| C4 | 1640:52 | 1644:19 | 20.7 | 2046:57 | 2050:22 | 20.7 | 1557:35 | 1601:03 | 20.7 | C4 |
| D1 | 1640:52 | 1644:19 | - | 2046:57 | 2050:22 | 21.0 | 1557:35 | 1601:03 | 21.0 | D1 |
| D2 | 1650:47 | 1654:32 | 20.3 | 2056:49 | 2100:40 | 20.3 | 1607:31 | 1610:36 | 20.3 | D2 |
| D3 | 1650:47 | 1654:32 | 18.9 | 2056:49 | 2100:40 | 18.9 | 1607:31 | 1610:36 | 18.9 | D3 |
| D4 | 1701:10 | 1705:01 | 20.8 | 2107:18 | 2110:47 | 20.8 | 1617:14 | 1620:57 | 20.8 | D4 |
| E1 | 1701:10 | 1705:01 | 20.1 | 2107:18 | 2110:47 | 20.0 | 1617:14 | 1620:57 | 20.1 | E1 |
| E2 | 1711:45 | 1715:26 | 20.7 | 2117:31 | 2121:03 | 20.7 | 1627:40 | 1631:09 | 20.7 | E2 |
| E3 | 1711:45 | 1715:26 | 18.8 | 2117:31 | 2121:03 | 19.4 | 1627:40 | 1631:09 | 19.5 | E3 |
| E4 | 1721:52 | 1725:16 | 18.5 | 2127:29 | 2131:01 | 20.6 | 1637:34 | 1641:14 | 20.6 | E4 |
| F1 | 1721:52 | 1725:16 | 20.1 | 2127:29 | 2131:01 | 20.1 | 1637:34 | 1641:14 | 20.1 | F1 |
| F2 | 1731:46 | 1735:38 | 20.7 | 2137:31 | 2141:22 | 20.7 | 1647:44 | 1651:34 | 20.7 | F2 |
| F3 | 1731:46 | 1735:38 | 20.3 | 2137:31 | 2141:22 | 19.9 | 1647:44 | 1651:34 | 21.1 | F3 |
| F4 | 1742:18 | 1745:53 | 19.9 | 2148:01 | 2151:43 | 19.9 | 1658:13 | 1701:44 | 19.9 | F4 |

LP ARRAY SINUSOIDAL CALIBRATIONS (CONTINUED)

| SUBARRAY | Long-Period Array Sinusoidal Calibration Signal Times and Input Amplitudes | | | | | | | | | SUBARRAY |
|---|---|---|---|---|---|---|---|---|---|---|
| | Day 148: 28 May 73 | | | Day 155: 4 June 73 | | | Day 162: 11 June 73 | | | |
| | Start Time (GMT) | Stop Time (GMT) | Input Ampl. µm P-P | Start Time (GMT) | Stop Time (GMT) | Input Ampl. µm P-P | Start Time (GMT) | Stop Time (GMT) | Input Ampl. µm P-P | |
| AO | 1504:47 | 1508:19 | 20.0 | 1438:04 | 1441:52 | 20.0 | 1514:00 | 1517:28 | 20.0 | AO |
| C1 | 1504:47 | 1508:19 | 19.2 | 1438:04 | 1441:52 | 19.1 | 1514:00 | 1517:28 | 19.2 | C1 |
| C2 | 1514:54 | 1518:43 | 108 | 1448:28 | 1451:55 | 108 | 1522:57 | 1526:41 | 108 | C2 |
| C3 | 1514:54 | 1518:43 | 20.4 | 1448:28 | 1451:55 | 20.4 | 1522:57 | 1526:41 | 20.5 | C3 |
| C4 | 1525:23 | 1528:58 | 20.7 | 1458:36 | 1502:00 | 20.7 | 1533:17 | 1536:53 | 20.7 | C4 |
| D1 | 1525:23 | 1528:58 | 21.0 | 1458:36 | 1502:00 | 21.0 | 1533:17 | 1536:53 | 21.1 | D1 |
| D2 | 1535:26 | 1538:56 | 20.3 | 1508:28 | 1512:17 | 20.3 | 1542:57 | 1546:42 | 19.6 | D2 |
| D3 | 1535:26 | 1538:56 | 18.9 | 1508:28 | 1512:17 | 18.9 | 1542:57 | 1546:42 | 18.9 | D3 |
| D4 | 1545:34 | 1549:17 | 20.8 | 1518:55 | 1522:27 | 20.7 | 1553:21 | 1557:13 | 20.7 | D4 |
| E1 | 1545:34 | 1549:17 | 20.1 | 1518:55 | 1522:27 | 20.0 | 1553:21 | 1557:13 | 20.1 | E1 |
| E2 | 1556:01 | 1559:38 | 20.7 | 1529:12 | 1532:41 | 20.7 | 1603:58 | 1607:23 | 20.6 | E2 |
| E3 | 1556:01 | 1559:38 | 19.4 | 1529:12 | 1532:41 | 19.4 | 1603:58 | 1607:23 | 19.5 | E3 |
| E4 | 1606:04 | 1609:32 | 20.6 | 1539:08 | 1542:34 | 20.6 | 1613:50 | 1617:26 | 20.6 | E4 |
| F1 | 1606:04 | 1609:32 | 20.1 | 1539:08 | 1542:34 | 20.1 | 1613:50 | 1617:26 | 20.1 | F1 |
| F2 | 1616:02 | 1619:39 | 20.7 | 1549:04 | 1552:34 | 20.7 | 1623:56 | 1627:35 | 20.7 | F2 |
| F3 | 1616:02 | 1619:39 | 21.1 | 1549:04 | 1552:34 | 21.1 | 1623:56 | 1627:35 | 21.0 | F3 |
| F4 | 1626:19 | 1629:51 | 19.9 | 1559:15 | 1602:38 | 19.6 | 1634:15 | 1637:46 | 19.9 | F4 |

LP ARRAY SINUSOIDAL CALIBRATIONS (CONCLUDED)

| SUBARRAY | Long-Period Array Sinusoidal Calibration Signal Times and Input Amplitudes | | | | | | SUBARRAY |
|---|---|---|---|---|---|---|---|
| | Day 170: 19 June 73 | | | Day 176: 25 June 73 | | | |
| | Start Time (GMT) | Stop Time (GMT) | Input Ampl. μm P-P | Start Time (GMT) | Stop Time (GMT) | Input Ampl. μm P-P | |
| AO | 1732:12 | 1735:45 | 20.0 | 1616:56 | 1620:30 | 20.0 | AO |
| C1 | 1732:12 | 1735:45 | 19.2 | 1616:56 | 1620:30 | 19.1 | C1 |
| C2 | 1742:21 | 1746:09 | 108 | 1627:07 | 1630:55 | 108 | C2 |
| C3 | - | - | - | 1627:07 | 1630:55 | 20.5 | C3 |
| C4 | 1752:50 | 1756:38 | 20.7 | 1637:36 | 1641:12 | 20.7 | C4 |
| D1 | 1752:50 | 1756:38 | 21.0 | 1637:36 | 1641:12 | 21.1 | D1 |
| D2 | 1803:06 | 1806:38 | 20.3 | 1647:41 | 1651:24 | 20.2 | D2 |
| D3 | 1803:06 | 1806:38 | 18.9 | 1647:41 | 1651:24 | 18.9 | D3 |
| D4 | 1813:17 | 1818:05 | 20.6 | 1658:04 | 1701:36 | 20.7 | D4 |
| E1 | 1813:17 | 1818:05 | 20.1 | 1658:04 | 1701:36 | 20.1 | E1 |
| E2 | 1823:50 | 1827:15 | 20.7 | 1708:21 | 1711:58 | 20.6 | E2 |
| E3 | 1823:50 | 1827:15 | 19.4 | 1708:21 | 1711:58 | 19.4 | E3 |
| E4 | 1833:43 | 1837:14 | 20.6 | 1718:26 | 1721:58 | 20.6 | E4 |
| F1 | 1833:43 | 1837:14 | 20.1 | 1718:26 | 1721:58 | 20.1 | F1 |
| F2 | 1843:44 | 1847:14 | 19.2 | 1728:28 | 1732:05 | 20.7 | F2 |
| F3 | 1843:44 | 1847:14 | 21.1 | - | - | - | F3 |
| F4 | 1853:55 | 1857:34 | 19.9 | 1738:47 | 1742:12 | 19.8 | F4 |

TABLE XIV

PSEUDO-RANDOM BINARY SEQUENCE SEISMOGRAPH CALIBRATIONS

| System | Date | Approximate Start Time (GMT) | Approximate Stop Time (GMT) | Binary Bit Duration (Sec.) |
|---|---|---|---|---|
| SP | 11 Nov. 72 | 2146 | 2154 | 0.1 |
| SP | 15 Jan. 73 | 1818 | 1826 | 0.1 |
| SP | 15 Feb. 73 | 2107 | 2115 | 0.1 |
| LP | 21 Feb. 73 | 1849 | 1917 | 5.0 |
| LP | 15 Mar. 73 | 2158 | 2324 | 10.0 |
| SP | 19 Mar. 73 | 2021 | 2028 | 0.1 |
| LP | 15 Apr. 73 | 1519 | 1602 | 5.0 |
| SP | 17 Apr. 73 | 2319 | 2326 | 0.1 |
| SP | 15 May 73 | 1438 | 1445 | 0.1 |
| LP | 15 May 73 | 1351 | 1435 | 5.0 |
| SP | 16 Jun. 73 | 1022 | 1030 | 0.1 |
| LP | 16 Jun. 73 | 1042 | 1126 | 5.0 |

the PDP-7 computer using the appropriate telemetry commands. Program MASPOS maintains each seismometer mass to within ± 1.4 mm from its center position. Similarly, the seismometers' natural frequencies are maintained to within 20 ± 1 seconds/cycle by program FREECK.

The usefulness of performing this calibration remotely is shown by the large number of adjustments required. A total of 1116 adjustments were necessary; an average of 13.4 per week. The majority (80.7%) were to recenter the seismic mass.

3.3.2.5 SEM DC Offset Measurement

Program DCOFF measures the dc offset in millivolts of the SEM input and multiplexer channel circuits. The 346 SEM SP input and 346 SEM SP multiplexer circuits are checked monthly. All measurements from each subarray SEM are printed out by the PDP-7 and those channels with dc offsets exceeding 0 ± 5mV are marked for maintenance attention.

3.3.2.6 Subarray Battery Voltage

Program BATCK is used to measure the battery voltage of the subarray power system each week. Measurements exceeding 30 ± 1 volts are flagged for maintenance action.

3.3.2.7 Develocorder

Program DEVCAL is used daily to provide sinusoidal calibration signals on each seismograph trace recorded by the Develocorder(s). The nominal 400-nm, one-hertz-sinusoidal seismograph calibration output is divided by 10 to provide a nominal 40 nm peak-to-peak recorded signal to calibrate the amplitude of seismic signal responses.

3.3.3 Detection of Defective Channels

When during the array monitoring and calibration activities the measured channel responses exceed the tolerances established for a particular channel, an equipment defect is reported to maintenance and to selected users of the array data. Normal channel responses to sinusoidal calibrations are shown in Table XV, where A (volts) is the analog value, A (digital) is the digital value in decimal, and Y is the corresponding equivalent earth motion input. The Defective Signal Channel Status Report is distributed each week to all agencies authorized by VSC.

Table XVI indicates an incidence of 1561 defective channels detected between 1 Dec 71 and 30 Jun 73 or an average of 18.81 per week. The majority of these (71%) relate to LP

TABLE XV

LASA SEISMOGRAPH CALIBRATION RESPONSE TOLERANCES

| CHANNEL IDENT. | TC | Peak-to-Peak Sinusoidal Amplitudes | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $A_{nom}$ Volts | $A_{max}$ Volts | $A_{min}$ Volts | $A_{nom}$ Digital | $A_{max}$ Digital | $A_{min}$ Digital | $Y_{nom}$ | $Y_{max}$ | $Y_{min}$ |
| SPZ | 06[1] | 7.91 | 9.09 | 6.72 | 9257 | 10638 | 7864 | 395nm | 455nm | 336nm |
| SPAZ | 06[1] | .25 | .289 | .214 | 293 | 407 | 236 | 395nm | 455nm | 336nm |
| SPIZ | 06[1] | 7.91 | 9.09 | 6.72 | 9257 | 10638 | 7864 | 395nm | 455nm | 336nm |
| SPTZ | 06[1] | 7.91 | 9.09 | 6.72 | 9257 | 10638 | 7864 | 395nm | 455nm | 336nm |
| SPTN | 06[1] | 7.91 | 9.09 | 6.72 | 9257 | 10638 | 7864 | 395nm | 455nm | 336nm |
| SPTE | 06[1] | 7.91 | 9.09 | 6.72 | 9257 | 10638 | 7864 | 395nm | 455nm | 336nm |
| LPZ | 20[2] | 6.98 | 7.98 | 5.99 | 8168 | 9339 | 7010 | 20.0μm | 22.8μm | 17.1μm |
| LPH | 20[2] | 6.98 | 7.98 | 5.99 | 8168 | 9339 | 7010 | 20.0μm | 22.8μm | 17.1μm |
| LPAZ | 20[3] | 2.77 | 3.19 | 2.34 | 3242 | 3733 | 2738 | 252μm | 290μm | 213μm |
| LPAH | 20[3] | 2.77 | 3.19 | 2.34 | 3242 | 3733 | 2738 | 252μm | 290μm | 213μm |
| LPWZ | 20[2] | 1.10 | 1.26 | 0.93 | 1287 | 1475 | 1088 | 20.0μm | 22.9μm | 16.9μm |
| LPWH | 20[2] | 1.10 | 1.26 | 0.93 | 1287 | 1475 | 1088 | 20.0μm | 22.9μm | 16.9μm |

Note 1. Amplitude measurements corrected for response to 400nm, 1s calibration signal.
2. Amplitude measurements corrected for response to 20μm, 25s calibration signal.
3. Amplitude measurements corrected for response to 222μm, 25s calibration signal.

TABLE XVI

INCIDENCE OF DEFECTIVE SUBARRAY CHANNELS

December 1971 - June 1973

| SUBARRAY | CHANNELS | | |
|---|---|---|---|
| | SP | LP | METEOR |
| AO | 14 | 2 (54) | 0 |
| B1 | 14 | - | - |
| B2 | 25 | - | - |
| B3 | 19 | - | - |
| B4 | 20 | - | - |
| C1 | 12 | 11 (58) | - |
| C2 | 24 | 5 (77) | - |
| C3 | 8 | 4 (88) | - |
| C4 | 22 | 3 (46) | - |
| D1 | 11 | 4 (63) | - |
| D2 | 23 | 6 (93) | - |
| D3 | 11 | 3 (52) | - |
| D4 | 15 | 5 (92) | - |
| E1 | 7 | 1 (62) | 1 |
| E2 | 18 | 6 (51) | 1 |
| E3 | 21 | 3 (57) | - |
| E4 | 25 | 2 (79) | 0 |
| F1 | 32 | 5 (64) | 0 |
| F2 | 20 | 2 (93) | 0 |
| F3 | 21 | 2 (44) | 0 |
| F4 | 13 | 4 (43) | 0 |
| TOTALS | 375 | 68 (1116) | 2 |

seismometer positioning and are corrected remotely from LDC without maintenance attention. Thus 445 defective channels, an average of 5.36 per week, were reported. The defective channels detected during the final four months of the period are shown in Table XVII.

In addition to the amplitude response tolerances and the LP seismometer positioning tolerances already mentioned, the seismograph instrumentation is checked for signal distortion, polarity, offset, and phase.

### 3.3.4 Communications

The interface provided by the communications systems (Ref. 2) plays an important part in the success of the array operation. The structure of the 22 dedicated, 19.2 kilobaud, full-duplex telephone circuits connecting the array and maintenance center with the data center is shown in Figure 3.2.

Determination of data interruptions due to telephone circuit outages is one responsibility of the LDC operations activity. All outages reported by data center personnel are assigned a ticket number to aid in accounting and identifying the data interruption. Weekly meetings are held with personnel from the major telephone companies, viz., Mountain Bell and Mid-Rivers Coop., to review and describe all outages.

The TELCO outages of each subarray are summarized in Table XVIII where the subarrays are listed in order of their TELCO circuit availability percentage. The total communications outage equalled 918.35 hours which results in an average TELCO circuit availability of 99.68%. The major array data interruptions due to communications and power systems are identified in Table XIX. The extended outages exceeding a two-hour duration are listed for the period March-June 1973 in Table XX.

TABLE XVII

INCIDENCE OF DEFECTIVE SUBARRAY CHANNELS

March - June 1973

| SUBARRAY | CHANNELS | | |
|---|---|---|---|
| | SP | LP | METEOR |
| AO | 2 | 0 (7) | 0 |
| B1 | 1 | - | - |
| B2 | 3 | - | - |
| B3 | 0 | - | - |
| B4 | 4 | - | - |
| C1 | 4 | 0 (10) | - |
| C2 | 2 | 0 (15) | - |
| C3 | 1 | 4 (14) | - |
| C4 | 1 | 0 (7) | - |
| D1 | 1 | 3 (9) | - |
| D2 | 3 | 0 (15) | - |
| D3 | 0 | 0 (5) | - |
| D4 | 2 | 0 (13) | - |
| E1 | 0 | 0 (7) | 0 |
| E2 | 1 | 1 (7) | 0 |
| E3 | 3 | 0 (6) | - |
| E4 | 0 | 1 (12) | 0 |
| F1 | 1 | 1 (7) | 0 |
| F2 | 0 | 1 (7) | 0 |
| F3 | 4 | 1 (10) | 0 |
| F4 | 3 | 0 (3) | 0 |
| TOTALS | 36 | 12 (154) | 0 |

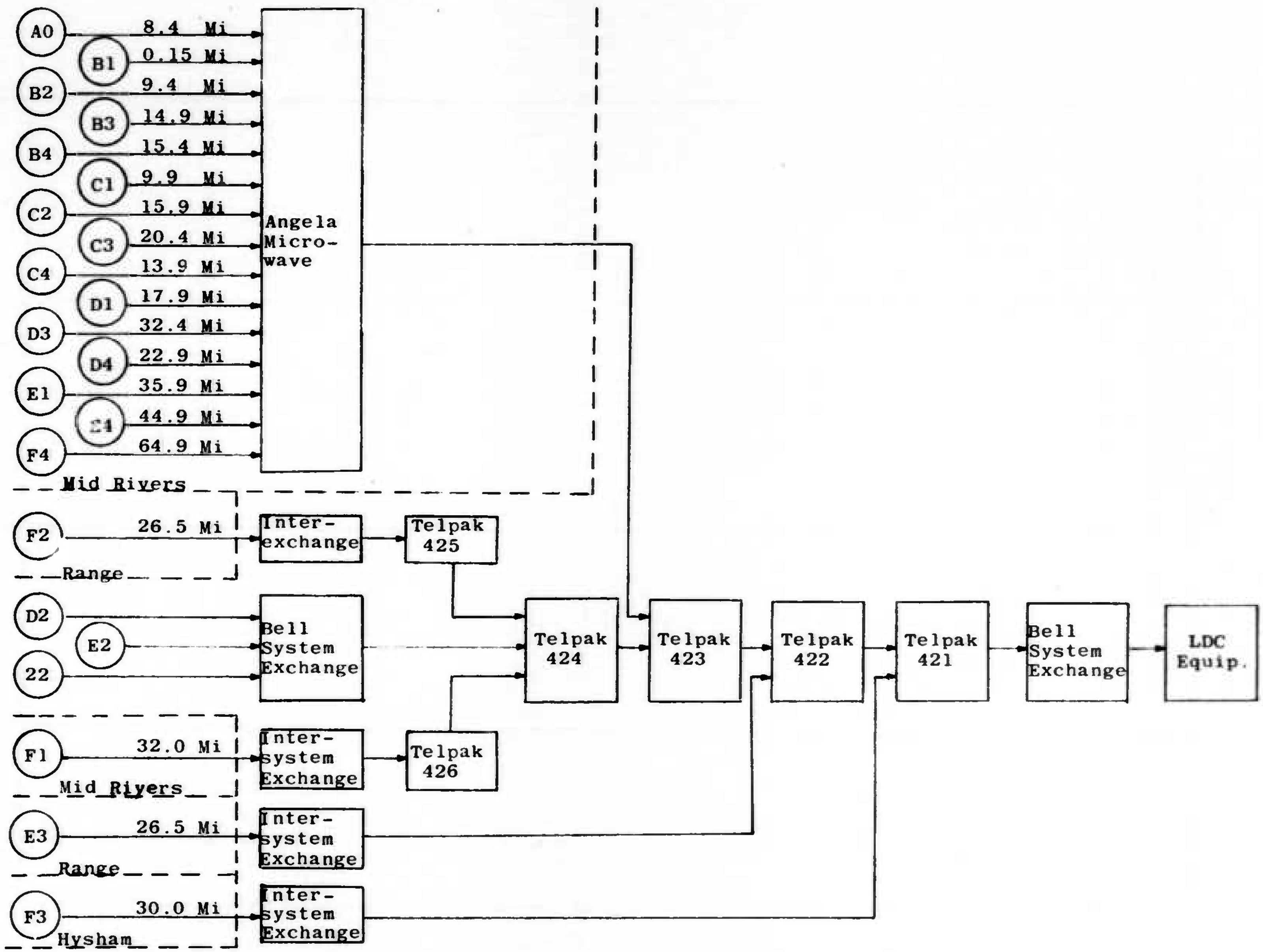



Figure 3.2 Array Communications Structure

TABLE XVIII

ARRAY COMMUNICATIONS OUTAGE STATISTICS

December 1971 - June 1973

| SUB ARRAY | CIRCUIT NO. | TOTAL OUTAGE TIME (h) | CIRCUIT AVAILABILITY (%) |
|---|---|---|---|
| D2 | 2715 | 4.750 | 99.966 |
| F2 | 2721 | 8.167 | 99.941 |
| B3 | 2705 | 8.733 | 99.937 |
| B2 | 2710 | 12.767 | 99.908 |
| E2 | 2720 | 13.083 | 99.906 |
| B1 | 2701 | 16.317 | 99.882 |
| D1 | 2714 | 17.200 | 99.876 |
| B4 | 2707 | 17.967 | 99.870 |
| C1 | 2708 | 20.067 | 99.855 |
| C2 | 2709 | 26.600 | 99.808 |
| AO | 2704 | 30.550 | 99.780 |
| F1 | 2719 | 34.600 | 99.751 |
| D4 | 2713 | 35.617 | 99.743 |
| D3 | 2713 | 46.467 | 99.665 |
| E4 | 2717 | 54.150 | 99.610 |
| E3 | 2716 | 56.667 | 99.592 |
| C4 | 2706 | 63.233 | 99.544 |
| F3 | 2702 | 82.733 | 99.404 |
| C3 | 2711 | 107.700 | 99.224 |
| E1 | 2718 | 116.300 | 99.162 |
| F4 | 2703 | 144.683 | 99.957 |

TABLE XIX

MAJOR ARRAY DATA INTERRUPTIONS DUE TO COMMUNICATIONS AND POWER SYSTEMS OUTAGES

December 1971 - June 1973

| Date | Duration (h:m) | Site/Circuit | Reason for Outage |
|---|---|---|---|
| 12/25/71 | 12:26 | C4 - 2706 | Damaged Bridle Wire at Subarray |
| 12/26/71 | 10:38 | C4 - 2706 | Damaged Bridle Wire at Subarray |
| 12/27/71 | 13:53 | C4 - 2706 | Damaged Bridle Wire at Subarray |
| 01/18/72 | 12:53 | E1 - 2718 | Damaged Bridle Wire at Subarray |
| 01/23/72 | 14:28 | F4 - 2703 | Frost on Line |
| 02/12/72 | 14:22 | D3 - 2712 | Bad Oscillator at Toll Test |
| 06/18/72 | 12:50 | F4 - 2703 | Wire Wrap Near Subarray |
| 06/21/72 | 17:41 | F4 - 2703 | Wire Wrap Near Subarray and Toll Test on Defective Patch |
| 06/27/72 | 1:13 | Angela MW Sites | Angela MW Inverter Failure |
| 07/19/72 | 10:32 | C4 - 2706 | Hi-Lo Frequency Filter Damaged by Lightning |
| 08/20/72 | 23:24 | F2 - 2721 | No Commercial Power |
| 10/20/72 | 15:35 | D3 - 2712 | Broken Open Wire Line |
| 03/16/73 | 3:24 | All Sites Except D2, E2 E3, F1, F2, F3 | R1-W Power Supply Failure |
| 04/21/73 | 48:29 | F3 - 2702 | No Commercial Power |
| 04/21/73 | 33:56 | E4 - 2717 | No Commercial Power |
| 05/22/73 | 18:27 | D4 - 2713 | Open Wire Line Down |
| 06/17/73 | 67:12 | C3 - 2711 | Lightning Damage to Amp. Card in Modem. Repair Delayed Due to Bad Roads |
| 06/29/73 | 19:38 | C3 - 2711 | Hi-Lo Frequency Filter Inop. |

TABLE XX

EXTENDED ARRAY DATA INTERRUPTIONS DUE TO COMMUNICATIONS OUTAGES

March 73 - June 73

| Date | Duration (h:m) | Site/Circuit | Reason for Outage |
|---|---|---|---|
| 03/16/73 | 3:24 | All Sites Except D2,E2 E3,F1,F2,F3 | Microwave Relay (R1-W) Power Supply Failure |
| 04/03/73 | 3:20 | D1 | Problem at Angela Microwave |
| 04/09/73 | 5:18 | F4 | Frost on Line |
| 05/10/73 | 3:18 | D1 | Corrective Maint. at Angela MW |
| 05/02/73 | 3:57 | E3 & F3 | Telco Release for corrective maint. These outages repaired on 6/1/73 by replacement of amplifier modulator at Forsyth Repeater Station. |
| 05/07/73 | 3:21 | E3 | " " " " |
| 05/11/73 | 3:24 | E3 | " " " " |
| 05/11/73 | 2:50 | F3 | " " " " |
| 05/14/73 | 2:09 | E3 | " " " " |
| 05/16/73 | 2:04 | E3 & F3 | " " " " |
| 05/17/73 | 2:03 | E3 & F3 | " " " " |
| 05/31/73 | 5:45 | E3 & F3 | " " " " |
| 05/22/73 | 18:27 | D4 | Open Wire Line Down |
| 06/08/73 | 5:28 | E4 | Open Wire Line Problem |
| 06/17/73 | 67:12 | C3 | Lightning Damage to Amp. Card in Modem. Repair Delayed Due to Bad Roads |
| 06/29/73 | 19:38 | C3 | Hi-Lo Frequency Filter Inop. |

## SECTION IV

## ARRAY PERFORMANCE

### 4.0 Introduction

The Montana array has been divided into ten different systems. Installed at the subarrays are these five systems: SP seismograph, LP seismograph, meteorological, subarray electronics module, and power. The data center has these systems: 360 computer (Model 44), PDP-7 computer, digital, analog, and test and support. The performance measured for these systems is presented in this section.

### 4.1 Sensing Systems

The array's sensing systems include the SP seismograph, the LP seismograph, and the meteorological. The overall performance measure applied to each of these is array data availability. The percentage of time the array systems are on-line providing quality data determine the value of this measure. Data availabilities are calculated by combining the total subarray data interruption times shown in Table XI with the total sensor outage times reported on the Defective Signal Channel Status reports each week. The data availabilities for the six reporting periods of this contract are shown in Table XXI together with the statistics of the previous contract. The percentage of telephone circuit outages which offset all subarray systems and further reduce the effective system data availabilities are also shown in the table. Accumulating the six periods of the contract, the SP data availability has been 95.85% and the LP 94.54%; telco outage 0.32%.

#### 4.1.1 SP Seismograph

##### 4.1.1.1 General

The LASA SP array is composed of 344 active SP seismometer locations. A total of 366 SP seismograph channels originate from the 346 seismometers installed at these locations. Twenty attenuated outputs and two horizontal component outputs are obtained from twenty-one locations to produce the 366 channels. In addition to the attenuated signal obtained from the center hole of each subarray except D2 and E3 (at subarray D2 the attenuated signal is generated at hole location 26 instead of 10), an analog summation of selected SP seismometers is available from each subarray.

The SP seismometer locations have been standarized with a few exceptions. The standard LASA SP seismograph system consists of (1) an HS-10-1/A seismometer installed in either 200 ft. steel cased holes along the subarray radial



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TABLE XXI

ARRAY SENSING SYSTEM DATA AVAILABILITIES

| PERIOD | % DATA AVAILABILITY | | | % OUTAGE |
|---|---|---|---|---|
| | SP | LP | MET | TELCO |
| 3/73 - 6/73 | 98.6 | 97.5 | 99.1 | 0.46 |
| 12/72 - 2/73 | 98.0 | 92.6 | 99.8 | 0.03 |
| 9/72 - 11/72 | 94.6 | 91.4 | 99.7 | 0.11 |
| 6/72 - 8/72 | 94.3 | 94.9 | 99.2 | 0.52 |
| 3/72 - 5/72 | 95.4 | 97.4 | 98.9 | 0.23 |
| 12/72 - 2/72 | 93.3 | 93.2 | 100.0 | 0.50 |
| 12/71 - 11/72 | 96.7 | 98.6 | 99.2 | 0.45 |

legs or 500 ft. steel cased holes at the subarray central, (2) an RA-5 low noise parametric amplifier installed in a well head vault (WHV) for amplifying the damped seismometer output, (3) PE-23 cable buried over distances varying up to 3.5 km (except at one subarray where the distances vary up to 10 km) for transmission of the signals to the central terminal housing (CTH),(4) a near-unity-gain amplifier, which converts the high-level signal from a balanced to an unbalanced, single-ended signal for ease in handling during further processing, (5) a low-pass filter, which is flat to 5 hertz and then cuts off at a rate providing 30 db attenuation at 10 hertz, performs filtering for prevention of signal aliasing during later sampling at a 20 samples/sec rate, (6) a multiplexer merges all the SP seismograph signals from a particular subarray into one data stream, and (7) an analog-to-digital converter and a buffer storage shift register prepare the digital data for transmission from the subarray CTH to the LDC.

The exceptions to the standard sensor are indicated in the array Status Report (Ref. 3) and described here briefly. At subarray D1,six of the seismometers are in uncased holes, one in a plastic-cased hole and six in near-surface installations at a depth of 10 feet. At subarray D2, the 500 ft. center hole contains a tri-axial seismometer, two locations (holes 23 and 62) contain an improved sensor package composed of an HS-10-1/B seismometer and an Ithaco amplifier in a stainless steel case, and one location (hole 46) has an experimental sensor consisting of an HS-10-1/A seismometer and an RA-5 amplifier in a common case. Also, the WHV electronics differ at subarrays B1, F3, and E3.

#### 4.1.1.2 Performance Monitoring Using TESP.

Performance monitoring from the automatic remotely controlled sinusoidal calibrations of the 346 SP seismograph channels using PDP-7 program TESP has shown an average channel sensitivity of 20.24 mV/nm at one-second periods with an average standard deviation of 1.20 mV/nm during the nineteen months of this reporting period. For the final four months these channel sensitivity statistics were 19.99 and 0.86 respectively. A summary of the test results obtained each week since March 5 is shown in Table XXII where the statistics are compared with those of previous periods.

Improvement of the SP array performance is reflected by the decrease in average standard deviation of the seismographs'sensitivities to 1.20 mV/nm for this contract period compared with the previous contract average of 1.69 mV/nm. Figure 4.1 plots the SP array seismograph sensitivity mean and standard deviation as measured each week throughout the contract period. This plot reflects only the long-term stability of the seismograph channels and not the short-term. The weekly sensitivity calibration is made at approximately

TABLE XXII

SP ARRAY PERFORMANCE TESTING SENSITIVITY STATISTICS

| DATE | NO. SENSORS | SENS. MEAN mV/nm | SENS. σ mV/nm | SENS. MAX. mV/nm | SENS. MIN. mV/nm | SENS. DEV. mV/nm |
|---|---|---|---|---|---|---|
| 3/5 | 346 | 20.09 | 0.76 | 22.28 | 16.54 | 5.74 |
| 3/12 | 346 | 20.16 | 0.68 | 22.96 | 16.94 | 6.02 |
| 3/19 | 346 | 20.12 | 0.57 | 22.52 | 18.49 | 4.03 |
| 3/26 | 346 | 20.16 | 0.77 | 22.81 | 18.03 | 4.78 |
| 4/2 | 346 | 20.18 | 0.69 | 23.39 | 18.47 | 4.92 |
| 4/9 | 346 | 20.12 | 0.65 | 22.59 | 17.56 | 5.03 |
| 5/16 | 346 | 20.21 | 0.77 | 22.64 | 18.30 | 4.34 |
| 4/23 | 330 | 20.11 | 0.70 | 22.89 | 16.68 | 6.21 |
| 4/30 | 344 | 20.13 | 0.73 | 22.61 | 18.02 | 4.59 |
| 5/7 | 346 | 19.91 | 1.15 | 26.81 | 16.89 | 9.92 |
| 5/14 | 346 | 19.63 | 1.06 | 23.42 | 15.15 | 8.27 |
| 5/21 | 346 | 19.92 | 0.95 | 22.69 | 16.53 | 6.16 |
| 5/28 | 345 | 20.04 | 0.92 | 23.03 | 11.44 | 11.59 |
| 6/4 | 342 | 20.09 | 1.02 | 23.30 | 14.05 | 9.25 |
| 6/11 | 344 | 19.35 | 1.21 | 23.13 | 12.19 | 10.94 |
| 6/18 | 342 | 20.02 | 0.96 | 23.73 | 10.67 | 13.06 |
| 6/25 | 342 | 19.64 | 1.08 | 23.06 | 15.21 | 7.85 |
| AVERAGE | 344.1 | 19.99 | 0.86 | 23.17 | 15.98 | 7.22 |
| PREVIOUS MAR-MAY AVERAGE | 325.2 | 20.54 | 1.33 | 24.86 | 12.43 | 12.43 |
| CONTRACT AVERAGE | 338.1 | 20.24 | 1.20 | 23.85 | 13.75 | 10.22 |
| PREVIOUS CONTRACT AVERAGE | 343.9 | 20.36 | 1.69 | 26.50 | 12.70 | 13.80 |

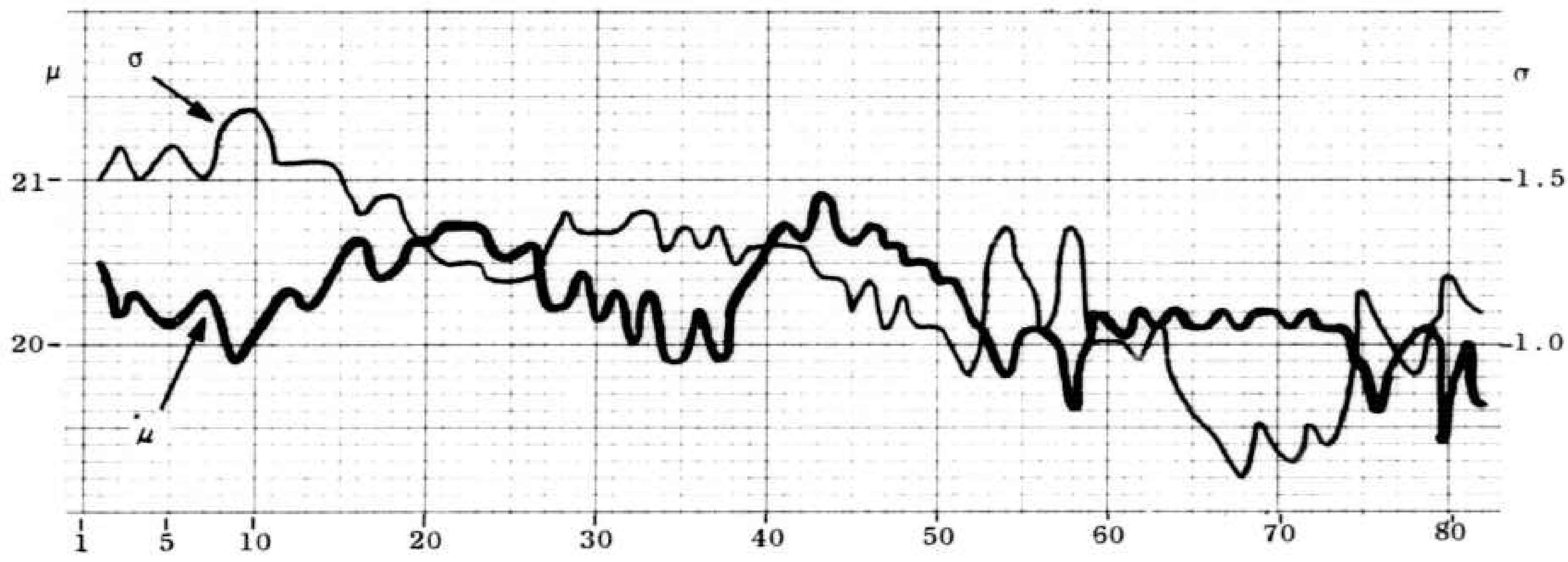


Figure 4.1 SP Array Seismograph Sensitivity Mean ($\mu$) and Standard Deviation ($\sigma$) in mV/nm at a one-second period between 7 Dec 71 and 25 Jun 73

the same time each Monday morning. Further improvement is reflected by the continuing increase in the number of channels within the ± 15 % sensitivity tolerance as shown in Figure 4.2 The improvement in amplitude stability of the SP array is attributed to (1) better maintenance practices on the RA-5 amplifier and (2) use of the new CTH SP Channel Gain Control.

#### 4.1.1.3 Single Channel Stability

The individual channel stability of the SP seismograph is measured from a statistical sample of 86 sensors. Six of these sensors were picked at random from subarray E3 and four were randomly sampled from each of the other 20 subarrays. Beginning 1 November 1971, the sensitivities of each of these 86 channels have been obtained from the daily printout of program TESP. At the end of each month a standard deviation of the sensitivity is calculated for each channel. This standard deviation value is used as a comparative measure of the individual channel stability. Table XXIII shows the results from 20 months use of this statistic.

Assuming the distribution of an individual channel's sensitivity is normal or an approximate normal distribution. Table XXIII shows that for a large majority of SP seismographs the measured sensitivity can be expected to be within 1 mV/nm of the instrument's mean sensitivity.

The variation in the percentage of sensors with a standard deviation less than .3333 mV/nm is attributed to environmental stress on the RA-5 amplifier. During a month when extreme temperature changes occur the standard deviation of a given sensor is higher than during a month of more constant temperature. So on the month of changing temperatures those sensors with a standard deviation just less than .3333 mV/nm will show a standard deviation higher than .3333 mV/nm and vice versa.

#### 4.1.1.4 Amplitude Frequency Response

The frequency response of the SP seismograph's amplitude output is now being measured by two different techniques. One is the established manual method of sine-wave inputs and determining the output/input amplitude ratio at each input frequency. The other technique differes by using a PRBS input to generate the broad band of input frequencies.

Measurement of the SP seismograph frequency response using a sine-wave generator at the subarray CTH was completed at sixteen subarrays with 251 seismograph channels. Figure 4.3 shows the mean and the mean ± 3 standard deviations response curves for the entire SP array as measured during the period 20 Oct 70 (D3) and 12 Jun 73 (AO). The average age of the data used in preparing these sensitivity plots is 14.4 months. The sensitivities are calculated using the

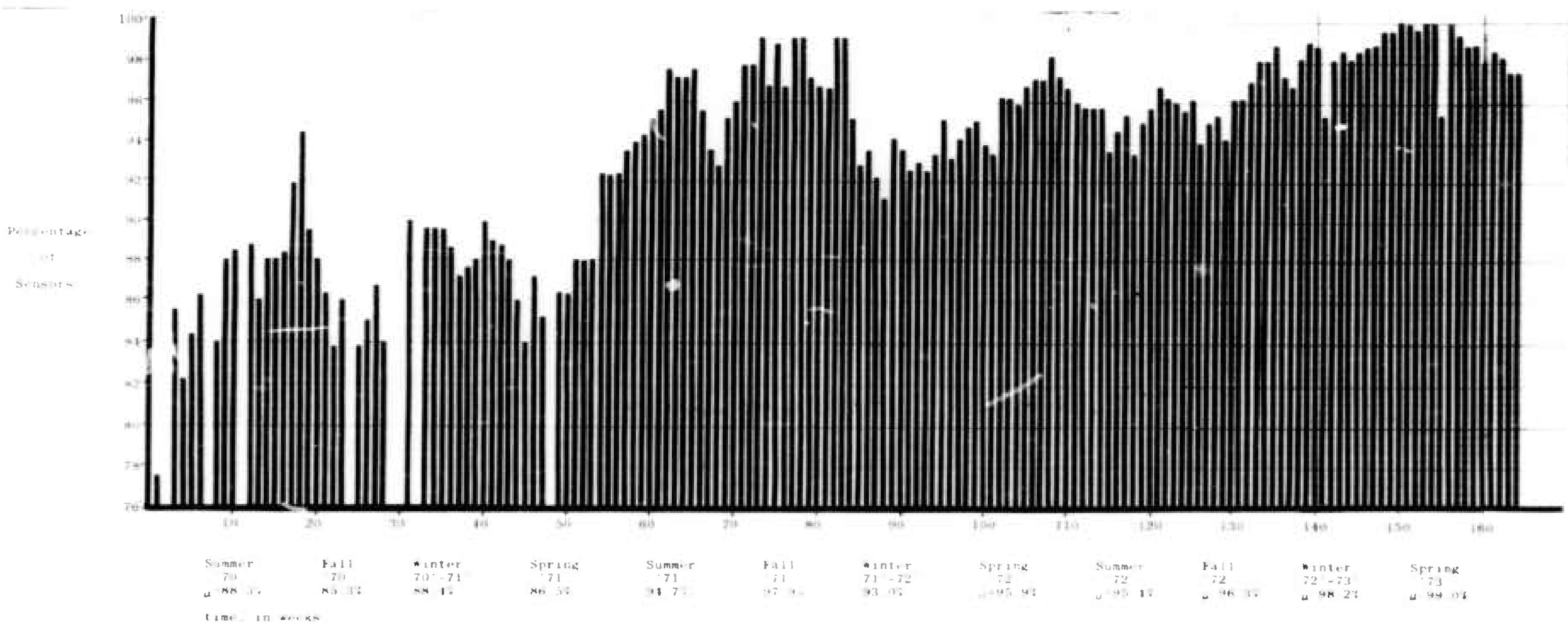


Figure 4.2  Percentage Distribution of SP Sensors Within ± 15% Sensitivity Tolerance

TABLE XXIII

DISTRIBUTION OF THE STANDARD DEVIATIONS OF 86 LASA SP CHANNELS

| MONTH | MEAN S in mV/nm | MAXIMUM S in mV/nm | MINIMUM S in mV/nm | % <.3333 mV/nm |
|---|---|---|---|---|
| Nov 71 | 0.1831 | 1.072 | 0.0570 | 95.3 |
| Dec 71 | 0.2236 | 1.945 | 0.0277 | 86.0 |
| Jan 72 | 0.2902 | 1.306 | 0.0807 | 73.3 |
| Feb 72 | 0.2559 | 1.690 | 0.0630 | 80.2 |
| Mar 72 | 0.3075 | 2.050 | 0.0849 | 70.6 |
| Apr 72 | 0.2030 | 3.007 | 0.0415 | 93.0 |
| May 72 | 0.2629 | 1.025 | 0.0625 | 79.1 |
| Jun 72 | 0.2190 | 1.582 | 0.0370 | 91.9 |
| Jul 72 | 0.2613 | 1.348 | 0.0640 | 83.7 |
| Aug 72 | 0.2335 | 0.7292 | 0.0372 | 90.7 |
| Sep 72 | 0.3022 | 0.9937 | 0.0809 | 73.3 |
| Oct 72 | 0.2350 | 0.9708 | 0.0480 | 88.2 |
| Nov 72 | 0.1559 | 0.6781 | 0.0510 | 95.3 |
| Dec 72 | 0.3004 | 1.3650 | 0.0517 | 63.5 |
| Jan 73 | 0.3240 | 1.1340 | 0.0508 | 68.2 |
| Feb 73 | 0.2223 | 0.7827 | 0.0435 | 83.7 |
| Mar 73 | 0.1595 | 0.8190 | 0.0050 | 95.3 |
| Apr 73 | 0.1885 | 0.8374 | 0.0370 | 93.0 |
| May 73 | 0.2656 | 1.2660 | 0.0638 | 77.9 |
| Jun 73 | 0.2897 | 2.7700 | 0.0905 | 87.2 |

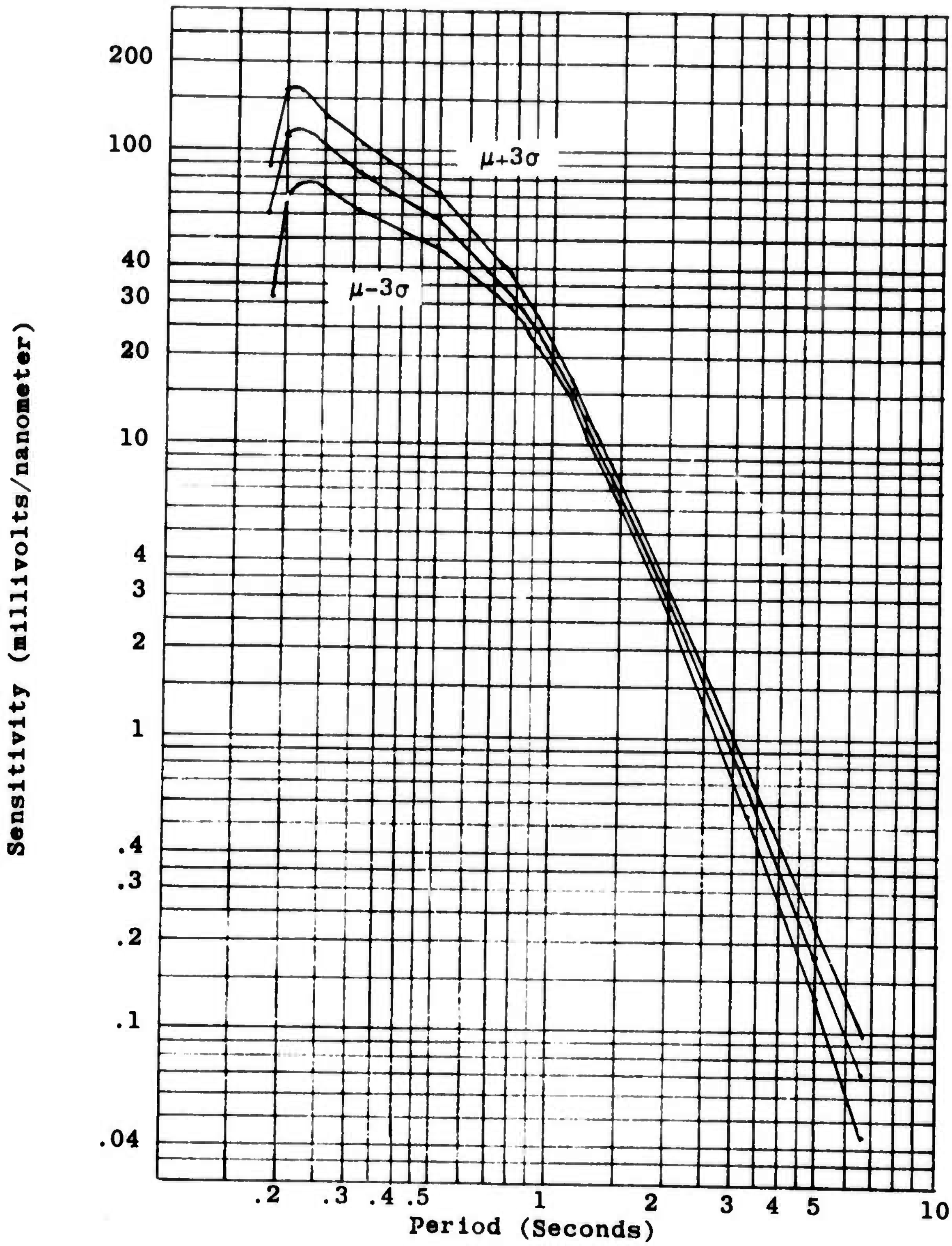


Figure 4.3 LASA SP Sensor Period vs Sensitivity Response Curves

measured values of output amplitude and input current amplitude and period and the nominal values of calibration constant and seismic mass. Table XXIV shows the average and the standard and maximum deviations of the channel sensitivities for each of the 16 frequencies used in the measurement.

Since completing the programs RPGONE and RPGTWO (see Section V), for the wide band calibration of the LASA SP sensors using a pseudo random bit sequence (PRBS), a test to determine the quality of the data has been in progress. Twenty-three sensors were chosen from subarrays B2 and B4 for use in this test because of the availability of recent data from a manual frequency response test on the sensors of these two subarrays. The manual frequency response test uses the following frequencies: 0.15, 0.20, 0.30, 0.50, 0.70. 0.80, 0.90, 1.00, 1.10, 1.20, 1.30, 1.50, 2.00, 3.00, and 5.00 Hz. Using linear interpolation the sensitivity from the PRBS test was determined at each of these frequencies and compared with the results of the manual test. At each of the 23 sensors the difference between the manual test and the PRBS test was determined and the percentage of this difference of the manual test was calculated. These results are summarized in Table XXV.

For frequencies greater than 0.30 Hz and less than 5.0 Hz the PRBS sensitivity is well within the measured manual sensitivity ± 10%. In the case of those frequencies less than or equal to 3 Hz the measured response is so low the degrees of accuracy of the reading of the manual test accounts for the larger precentage difference. The amplitude response for the manual test is read from a chart recorder to the nearest chart division. In the case of 0.15 Hz this degree of accuracy results in a possible error of ± 12.5%

A comparison of the one-hertz sensitivity from the PRBS test and the sensitivity from program TESP was also made. The average percentage difference between TESP sensitivity and PRBS sensitivity was 2.65%.

Figure 4.4 is a graph showing the gain of the PRBS test compared to the gain of the manual test of sensor B4-82. Since the amplitude of the manual test is read to the nearest chart division the actual amplitude could be anywhere between the shown amplitude ± 0.5 chart division. The gain was calculated for the shown amplitude +0.5 chart divisions and for the shown amplitude -0.5 chart division. The shaded area shows the limits of the manual test and the broken line the results of the PRBS test. In general the amplitude and hence the gain and sensitivity of the PRBS test are slightly higher than those from the manual test. In the case of the one sensor plotted in Figure 4.4 at 1 Hz the gain of the PRBS test is 0.857db higher than the manual test.

In conclusion the results of the test indicate a

TABLE XXIV

SEISMOGRAPH FREQUENCY RESPONSE OF SP ARRAY

| FREQUENCY (HERTZ) | SEISMOGRAPH CHANNEL SENSITIVITY (mV/nm) | | |
|---|---|---|---|
| | MEAN | STANDARD DEVIATION | MAXIMUM DEVIATION |
| 0.15 | 0.071 | 0.009 | 0.034 |
| 0.20 | 0.183 | 0.015 | 0.067 |
| 0.30 | 0.659 | 0.036 | 0.135 |
| 0.50 | 3.07 | 0.116 | 0.460 |
| 0.70 | 7.97 | 0.261 | 1.07 |
| 0.80 | 11.4 | 0.352 | 1.40 |
| 0.90 | 15.5 | 0.487 | 1.70 |
| 1.0 | 19.7 | 0.668 | 2.50 |
| 1.1 | 24.1 | 0.889 | 3.30 |
| 1.2 | 28.5 | 1.13 | 4.50 |
| 1.3 | 32.6 | 1.39 | 6.00 |
| 2.0 | 58.7 | 3.40 | 17.0 |
| 3.0 | 81.0 | 6.76 | 31.9 |
| 4.0 | 102.0 | 9.57 | 39.2 |
| 5.0 | 115.7 | 15.3 | 59.1 |
| 6.0 | 59.3 | 8.41 | 35.7 |

TABLE XXV

COMPARISON SP SEISMOGRAPH SENSITIVITY DIFFERENCE BETWEEN PRBS AND MANUAL FREQUENCY RESPONSE TESTS

| FREQUENCY (Hz) | MEAN DIFFERENCE in mV/nm | MEAN DIFFERENCE % |
|---|---|---|
| 0.15 | 0.01183 | 15.97 |
| 0.20 | 0.01965 | 11.70 |
| 0.30 | 0.06967 | 10.08 |
| 0.50 | 0.12005 | 3.74 |
| 0.70 | 0.34131 | 4.33 |
| 0.80 | 0.47684 | 4.25 |
| 0.90 | 0.99200 | 6.67 |
| 1.00 | 1.03619 | 5.34 |
| 1.10 | 0.58083 | 2.48 |
| 1.20 | 2.04606 | 7.52 |
| 1.30 | 1.41607 | 4.61 |
| 2.00 | 1.84430 | 3.38 |
| 3.00 | 4.43118 | 6.21 |
| 5.00 | 10.79535 | 10.88 |

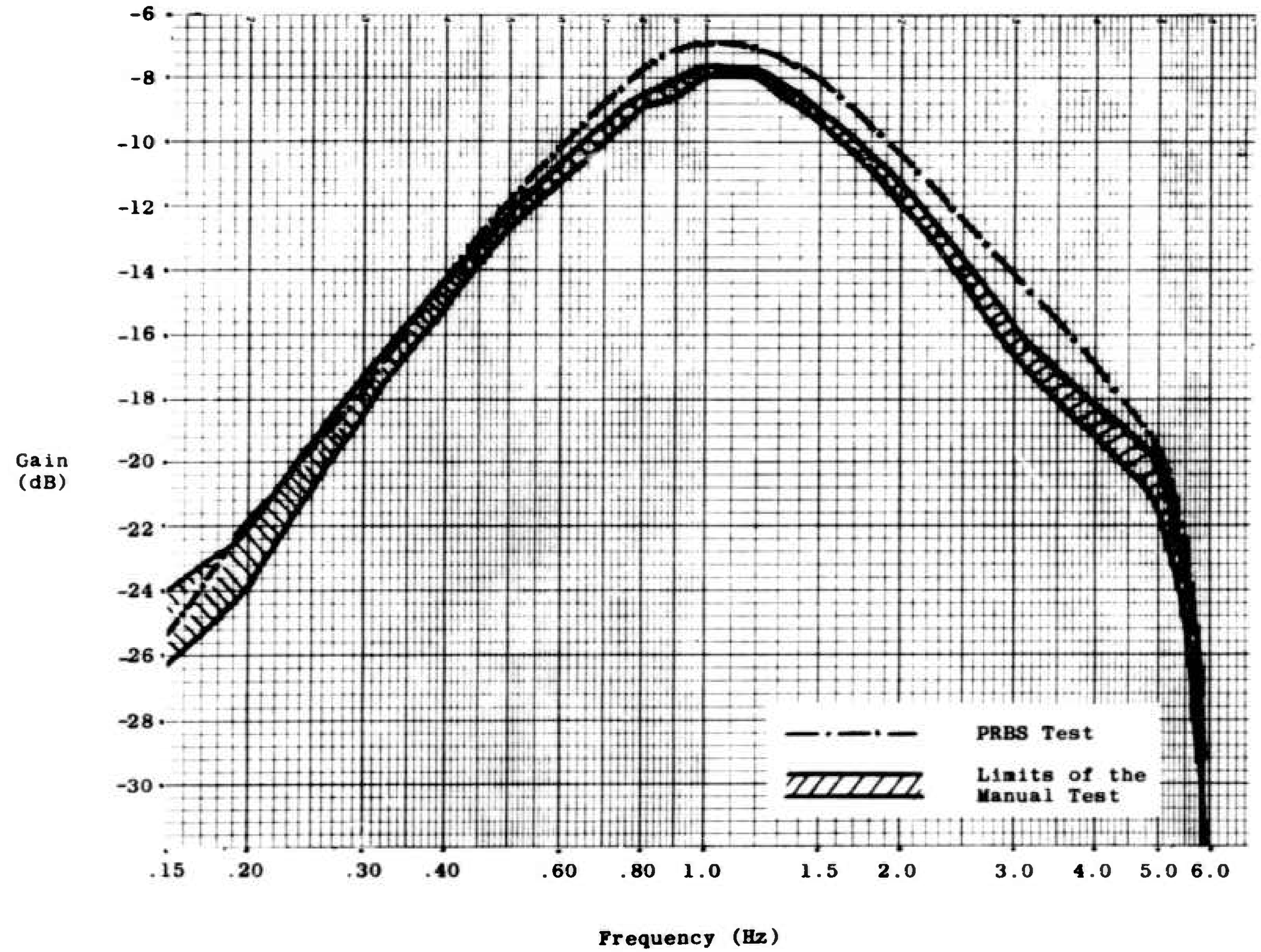


Figure 4.4 SP Sensor B4-82 Gain as Measured Using PRBS Compared with the Manual Frequency Response Test

high degree of reliability of data from the PRBS calibration of the LASA SP channels. The differences between the PRBS data and the data of the existing calibration methods are a result of: (1) measurement accuracy, (2) random noise, (3) the difference in methods. These differences are in most cases relatively small and a high degree of confidence in the data collected from the PRBS tests should be expected.

#### 4.1.1.5 Phase-Frequency Response

The phase of the seimograph at a particular frequency is the difference between the phases of a signal applied at the seismograph input and the signal obtained at its output. The frequency response of the phase is then the seismograph phase over a frequency range of interest. Using the PRBS calibration method, the phase response of the LASA SP seismographs is being studied. Response data has been collected on several seismograph channels. Figure 4.5 shows the phase response obtained for the B4-84 channel.

### 4.1.2 LP Seismograph

#### 4.1.2.1 General

The LASA LP array is composed of 17 sets of LP seismometers installed in the LP vault at the central site of each LASA subarray except those in the B-ring. Each set senses the vertical, north-south and east-west components of earth motion. The sensors at fifteen sites are adjusted for a nominal system sensitivity of 350 mV/$\mu$m at 25s. At subarray C2, where the three channels have been modified to prevent saturation from strong amplitude ground motion, the system sensitivity is adjusted for approximately 11 mV/$\mu$m at 25s. The standard amplifier channel filters for the LP seismographs at subarray C1 have been replaced with broadband filters, 12dB/octave high-cut, resulting in a system sensitivity of 55 mV/$\mu$m at 25s. The curves for all three LP seismograph responses are shown in Figure 1.3.

#### 4.1.2.2 Performance Monitoring Using TELP

The computer controlled sinusoidal calibrations performed on the 45 standard LASA LP seismograph channels during contract have indicated an average sensivitivy of 353.5 mV/$\mu$m at 25s with a standard deviation 19.3 mV/$\mu$m. For the final four months, these statistics were 350.3 and 20.4, respectively. The weekly test results are summarized in Table XXVI where they are compared with previous periods.

The amplitude response tolerance of the standard LP seismograph for 25-sec input signals is 350 $\pm$ 50 mV/$\mu$m. Figure 4.6 has plotted the percentage of the 45 standard channels within these tolerances each week since 8 Dec 70, a 134-week

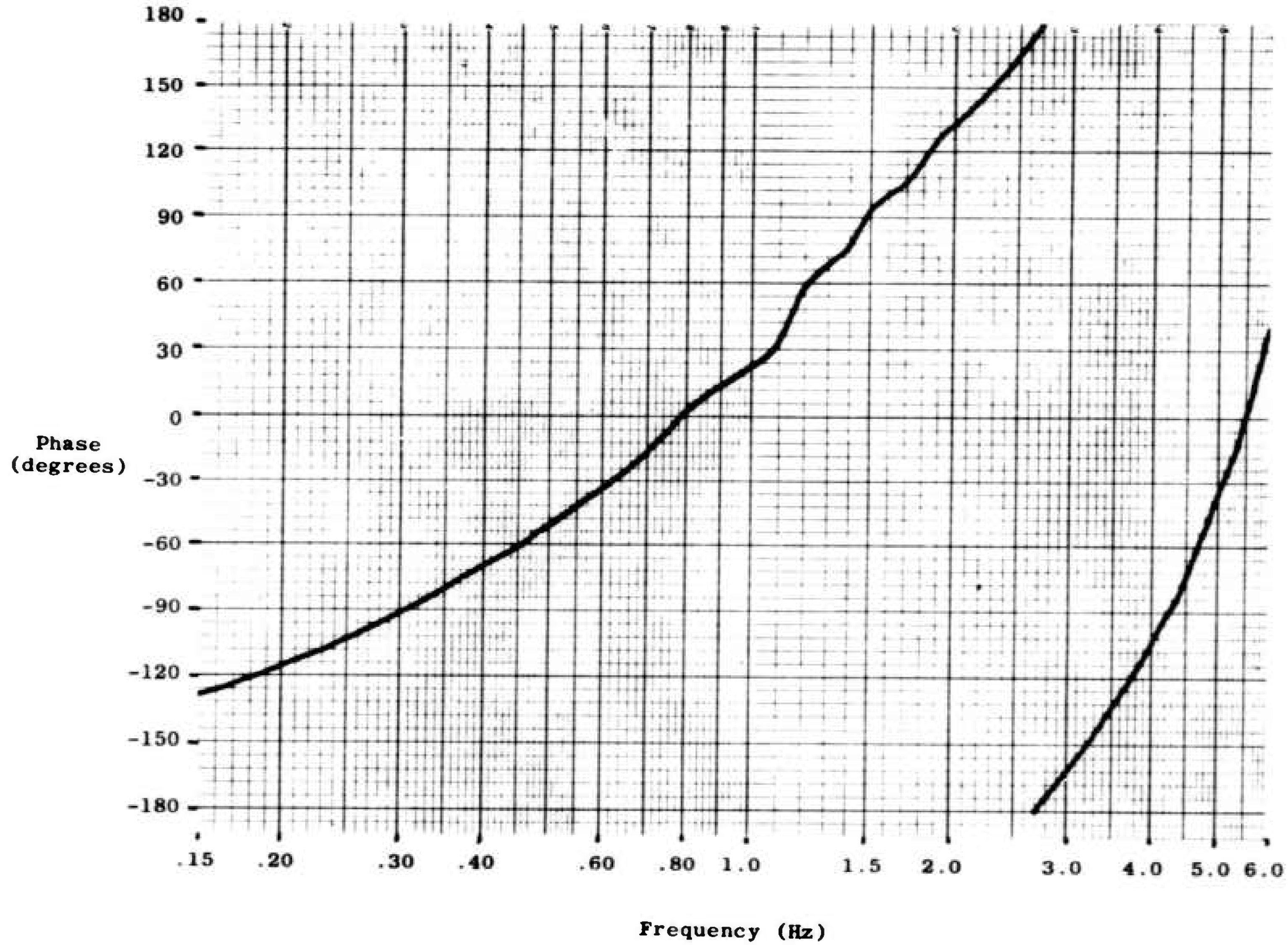


Figure 4.5 SP Sensor B4-82 Phase Response as Measured Using PRBS

TABLE XXVI

LP ARRAY PERFORMANCE TESTING SENSITIVITY STATISTICS

| DATE | NO. SENSORS | SENS. MEAN mV/nm | SENS. $\sigma$ mV/nm | SENS. MAX. mV/nm | SENS. MIN. mV/nm | SENS. DEV. mV/nm |
|---|---|---|---|---|---|---|
| 3/12 | 44 | 354.0 | 14.87 | 380.8 | 313.6 | 67.2 |
| 3/19 | 45 | 354.0 | 15.96 | 383.3 | 311.2 | 72.1 |
| 3/26 | 45 | 353.4 | 14.87 | 369.3 | 312.1 | 57.2 |
| 4/2 | 45 | 356.2 | 27.11 | 370.7 | 311.6 | 59.1 |
| 4/9 | 44 | 357.5 | 27.87 | 449.7 | 308.3 | 141.4 |
| 4/16 | 45 | 357.0 | 27.57 | 444.9 | 306.9 | 137.9 |
| 4/23 | 42 | 358.5 | 30.73 | 456.8 | 306.5 | 150.3 |
| 4/30 | 45 | 352.3 | 17.72 | 389.6 | 307.7 | 81.9 |
| 5/7 | 45 | 349.5 | 21.13 | 407.9 | 306.6 | 101.3 |
| 5/14 | 45 | 348.9 | 16.10 | 382.1 | 310.1 | 71.9 |
| 5/21 | 45 | 346.4 | 18.28 | 375.9 | 304.0 | 71.9 |
| 5/28 | 45 | 344.5 | 16.42 | 378.8 | 302.9 | 75.9 |
| 6/4 | 45 | 345.2 | 18.75 | 400.7 | 304.7 | 96.0 |
| 6/11 | 45 | 341.9 | 20.98 | 381.2 | 259.9 | 121.3 |
| 6/18 | 44 | 344.2 | 20.54 | 404.0 | 300.8 | 103.2 |
| 6/25 | 45 | 341.3 | 18.19 | 382.8 | 301.4 | 81.3 |
| AVERAGE | 44.6 | 350.3 | 20.44 | 397.4 | 304.3 | 93.1 |
| PREVIOUS MAR-MAY AVERAGE | 44.8 | 358.4 | 14.77 | 394.8 | 323.2 | 71.6 |
| CONTRACT AVERAGE | 44.4 | 353.5 | 19.29 | 403.1 | 307.3 | 97.9 |
| PREVIOUS CONTRACT AVERAGE | 44.6 | 356.1 | 18.8 | 403.0 | 312.0 | 90.0 |

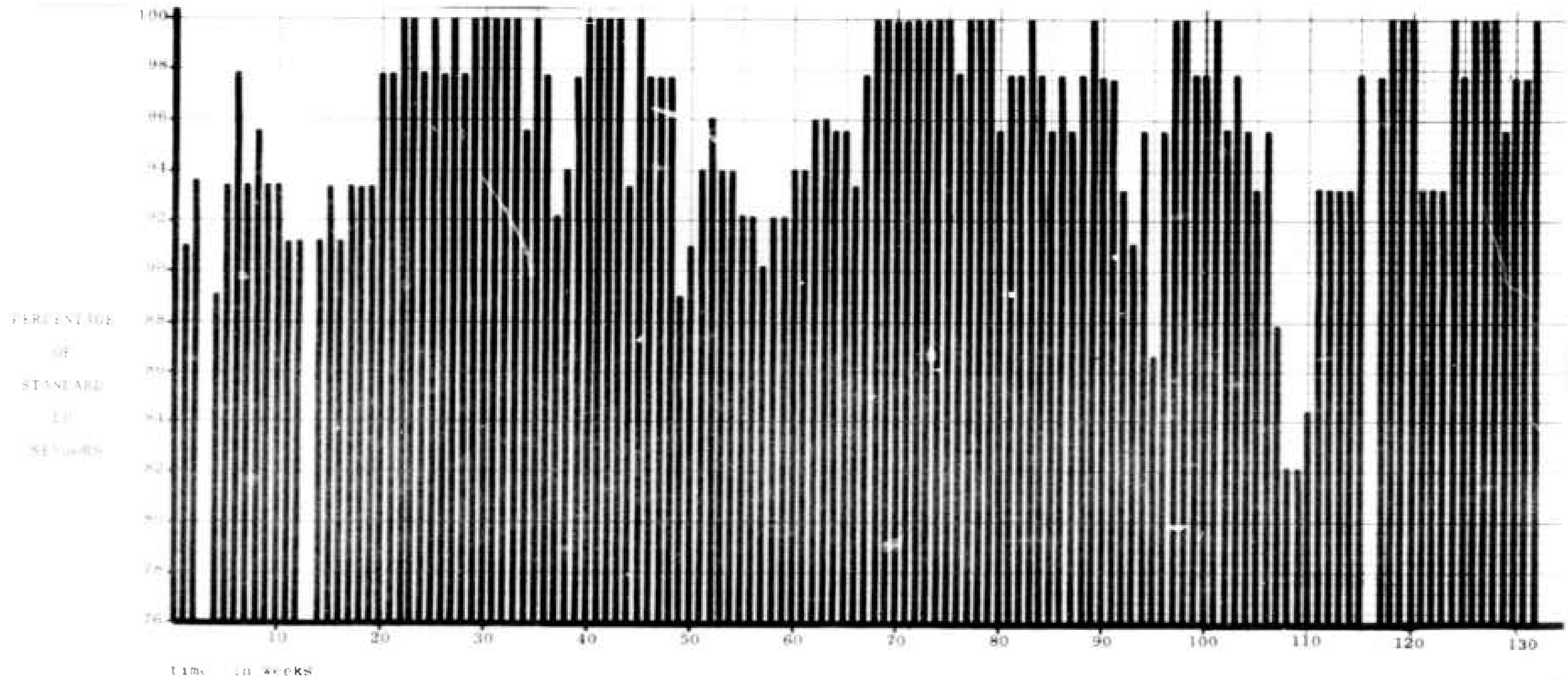


Figure 4.6 Percentage Distribution of LP Sensors Within ±50 mV/$\mu$m Sensitivity Tolerance

period. An increased incidence of Type II amplifier failures and moisture in the LP seismometer tanks account for the decreased percentage indicated near the end of the plot.

The LP array seismograph sensitivity mean and standard deviation as measured each week between 7 Dec 71 and 25 Jun 73 are plotted in Figure 4.7. The same annual cycle variation in sensitivity has been evident throughout the previous two years, 1970-71. The rapid changes in standard deviation reflect the influence each of the LP channels has on the total array population of 45 channels as contrasted with the SP system curve shown in Figure 4.3 where the array population equals 346.

#### 4.1.2.3 Single Channel Stability

The individual LP seismograph amplitude stability was studied using the channel sensitivity statistics of each of the 45 seismographs which comprise the standard LASA LP array. The standard deviation of the sensitivity over the period from 1 Nov 71 through 25 Jun 73 was used to measure channel amplitude stability. The lower the standard deviation the higher the amplitude stability was assumed to be. During the 86-week test period thirteen of the 45 channels required adjustment or other maintenance action that changed their amplitude output. The sensitivity standard devations over the test period for the remaining 32 channels were determined with the following results:

minimum standard deviation, 7.50 mV/$\mu$m (best)
average standard deviation, 16.43 mV/$\mu$m
maximum standard deviation, 31.51 mV/$\mu$m (worst)

Of these channels 78.1% had standard deviations less than 20.0 mV/$\mu$m and 68.8% were less than 17.3 mV/$\mu$m.

Assuming the distribution of the LP channel sensitivity measurements is normal or nearly approximated by a normal distribution, 68.8% of the LP seismographs 99.7% of the readings will be within 50 mV/$\mu$m of the mean for a particular channel. Considering the extended duration of the test, the implied amplitude stability of each LP seismograph is high. Over short periods of time there is relatively little change in the output of an indivdual channel. Over extended time periods amplitude variations occur which are due to the environmental conditions associated with the seasonal changes Even with these environmental stresses this study of the LP seismograph indicated that a channel can be expected to drift within the presently specified tolerance limits barring no channel failure.

#### 4.1.2.4 Free Period/Mass Position

The free period and mass position of each of the 51

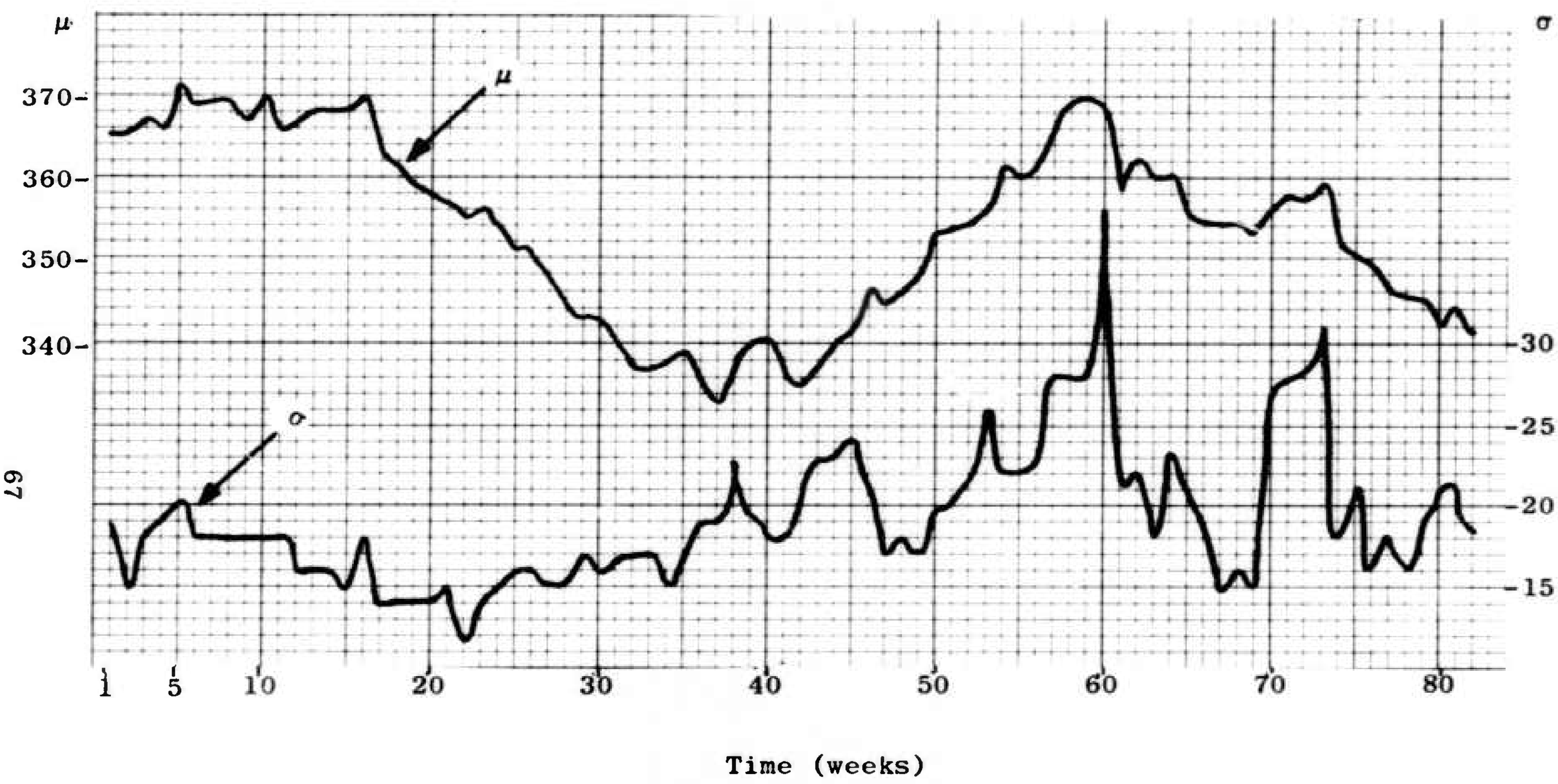


Figure 4.7 LP Array Seismograph Sensitivity Mean ($\mu$) and Standard Deviation ($\sigma$) in mV/$\mu$m at a 25-second period between 7 Dec 71 and 25 Jun 73

long-period seismometers are measured remotely each week at the LDC. These data indicate the average free period across the array over the last year of the contract to be 19.94 sec/cycle with a standard deviation of 0.15. The array summaries from these tests for the 17 weeks between 5 Mar and 25 Jun 73 are shown in Table XXVII. The average free period over the array for this final period measured 19.93 sec/cycle. The average weekly variation was |0.038| sec/cycle or 0.2%. During the 82-weekly tests a total of 213 adjustments or an average of 2.60 adjustments per test maintained the free periods to 20.0 ± 1.0 sec/cycle.

Mass position centering averaged-0.073mm while the average weekly variation measured |0.111| mm over the last 31 weeks of the contract. An average of 11.0 adjustments each week were necessary to maintain the 51 instrument masses within ± 1.4 mm of center.

### 4.1.3 Meteorological Instrumentation

The array has been augmented with meteorological measurement systems or weather stations, (Ref. 4), at subarray locations: AO, E1, E2, E4, F1, F2, F3, and F4. Each weather station measures wind direction, wind speed, and temperature and consists of an anemometer and associated bridge circuitry. In addition to the eight weather stations a tipping bucket rain gauge is intalled at subarray F3 and a barometric pressure sensor at subarray AO. The instrumentation, protected against damage from lightning strikes, is interconnected to the sub-array SEM for data transmission to the LDC. Operation of these systems is verified by the hourly weather report generated by the PDP-7 automatically during MOPS program operation. Calibration is performed on site using a portable test set which replaces the weather station sensors and provides selected fixed inputs covering the range of each circuit. A total of 13 such calibrations were performed during this past year.

## 4.2 Equipment

### 4.2.1 General

The equipment within the array systems are being evaluated on a continuing basis to identify their individual performance characteristics, to detect signs of aging, and to improve methods of detecting malfunctions. Progress of these evaluation efforts is reported in this section as information is collected and/or analyzed and made available for publication.

### 4.2.2 SP Seismometer, HS-10-1/A

The LASA SP seismograph uses the Geo Space, HS-10-1/A seismometer. This seismometer is a spring-mass device providing a velocity dependent output from a coil and magnetic transducer.

TABLE XXVII

LP ARRAY SEISMOGRAPH FREE PERIOD/MASS POSITION MEASUREMENT SUMMARY

| 1973 Test Date | Free Period, Sec/Cycle | | | No. Free Period Adjusts | Mass Position, mm | | | No. Mass Position Adjusts |
|---|---|---|---|---|---|---|---|---|
| | Average Before Adjusts | Average After Adjusts | Weekly Variation | | Average Before Adjusts | Average After Adjusts | Weekly Variation | |
| 3/5 | 20.03 | 20.03 | -0.00 | 0 | -0.21 | -0.16 | -0.15 | 6 |
| 3/12 | 19.94 | 19.98 | -0.10 | 4 | -0.14 | -0.24 | +0.02 | 4 |
| 3/19 | 19.93 | 19.95 | -0.06 | 1 | -0.26 | -0.18 | -0.02 | 5 |
| 3/26 | 19.97 | 19.97 | +0.02 | 0 | -0.27 | -0.21 | -0.09 | 6 |
| 4/2 | 19.94 | 19.94 | -0.02 | 0 | -0.19 | -0.17 | +0.02 | 4 |
| 4/9 | 19.94 | 19.94 | 0.00 | 0 | -0.11 | -0.11 | +0.07 | 8 |
| 4/16 | 19.93 | 19.93 | -0.02 | 0 | -0.20 | -0.14 | -0.10 | 3 |
| 4/23 | 19.91 | 19.91 | -0.01 | 0 | -0.09 | -0.11 | +0.00 | 5 |
| 4/30 | 19.91 | 19.95 | -0.00 | 1 | -0.05 | +0.04 | +0.06 | 9 |
| 5/7 | 19.85 | 19.88 | -0.10 | 1 | -0.00 | +0.05 | -0.05 | 8 |
| 5/14 | 20.02 | 19.98 | +0.14 | 2 | +0.38 | +0.14 | +0.33 | 13 |
| 5/21 | 19.94 | 19.92 | -0.05 | 1 | +0.10 | +0.03 | -0.03 | 9 |
| 5/28 | 19.91 | 19.91 | -0.02 | 0 | +0.20 | +0.13 | +0.17 | 14 |
| 6/4 | 19.93 | 19.96 | +0.02 | 2 | +0.16 | +0.24 | +0.03 | 8 |
| 6/11 | 19.90 | 19.90 | -0.06 | 0 | +0.47 | +0.26 | +0.23 | 14 |
| 6/18 | 19.89 | 19.90 | -0.01 | 1 | +0.30 | +0.19 | +0.04 | 12 |
| 6/25 | 19.91 | 19.91 | +0.01 | 1 | +0.52 | +0.25 | +0.33 | 15 |

A built-in calibrator forms a part of the seismometer.

Measurements collected and repairs made during the SP subarray rehabilitation program (para. 6.3.1) have better identified and improved the SP array's seismometer natural frequencies. Seismometer natural frequencies were measured at 169 sensor locations during this 19-month contract period. Measurements at the WHV location using the phase-reasonant or Lissajous pattern method is necessary because the high internal damping of the seismometer does not permit a free period impulse response that could be performed remotely. The natural frequency data collected have been combined with those collected throughout this measurement program to produce the frequency distribution shown in Figure 4.8. For a comparison Figure 4.9 shows the frequency distribution at the start of the contract. The recent plot now covers 238 or 68.8% of the array's seismometers.

The tolerance allowed is ± 10% so that all seismometer's natural frequencies measuring 1.0 ± 0.1 hertz are considered satisfactory. Seismometer replacements and field corrections, i.e., repositioning the seismometer in the well casing, have resulted in an estimated 90.8% of the instruments now operating within the tolerance limits. Of the 238 tested, 22 are presently operating out-of-limits; 9 of these are stuck at the bottom of the well casings and can't be readily corrected. Figure 4.10 indicated the natural frequency status of each seismometer data channel in the array.

Seismometer damping measurements have been made at 148 sensor locations since the collection of these data started. Previously the damping test was reported as satisfactory depending upon whether or not the damping ratio to critical was within 0.6 to 0.8. The frequency distribution of the damping measurement data collected from the 148 sensors or 42.8% of the array is plotted in Figure 4.11. These data indicate the array seismometers are somewhat underdamped from the nominal 0.7 damping ratio.

Since the internal damping of the HS-10-1A seismometer is significant enough to prevent seismometer oscillations from a single excitation pulse, the usual rate-of-oscillation-decay method of damping measurement cannot be used. However, the damping ratio can be determined by the overshoot method in which the mass is excited by a short-duration dc pulse applied to the calibration coil. The ratio of the positive half-cycle to the negative cycle output from the data coil determines the damping. An external damping resistance is selected so that the overshoot ratios corresponds to a damping ratio (to critical) range of .6 to .8. The external damping resistances are selected from a set consisting of these ohmic values: 51K, 82K, 110K and 120K.

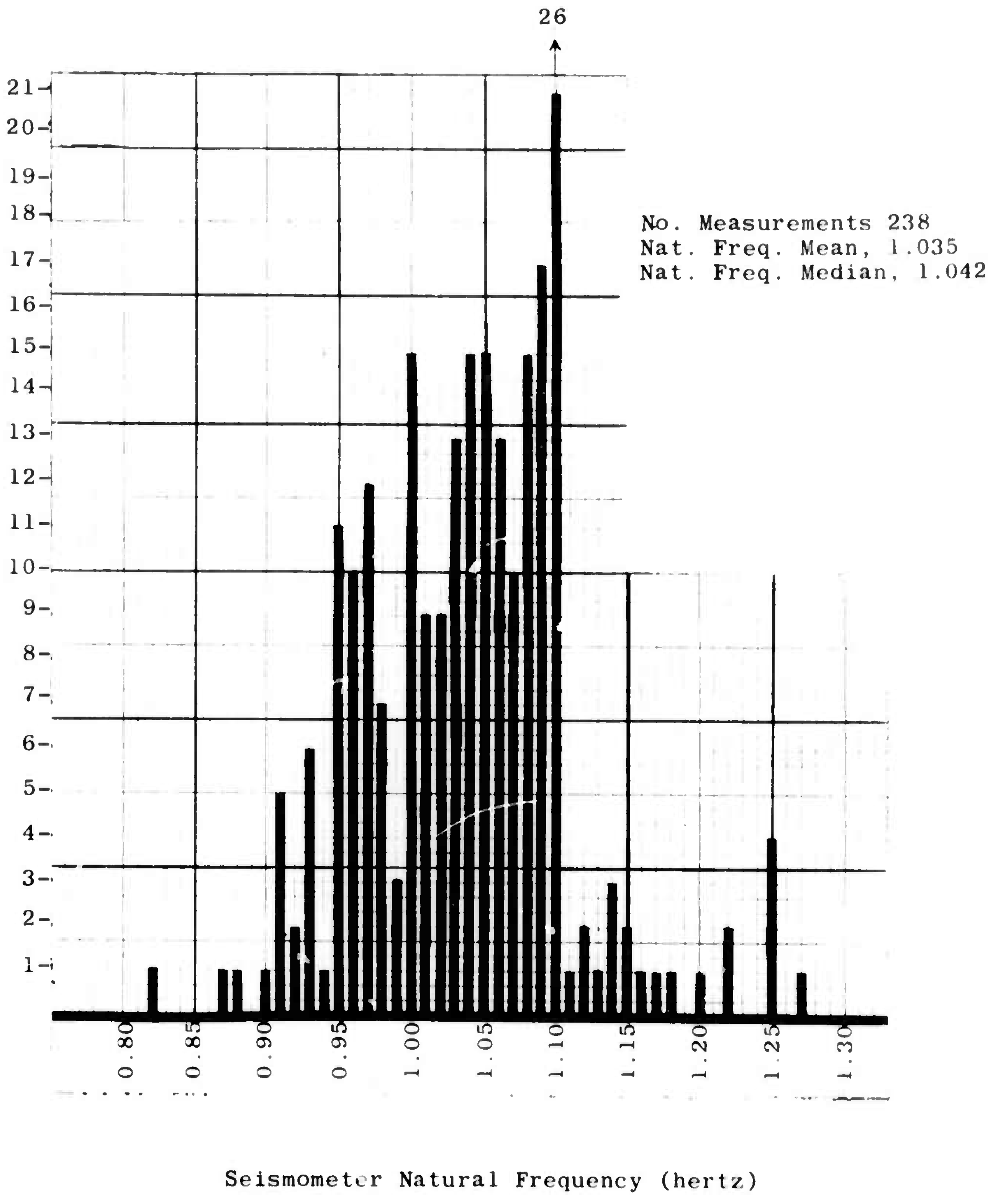


Figure 4.8 SP Seismometer Natural Frequency Distribution 5/70-6/73

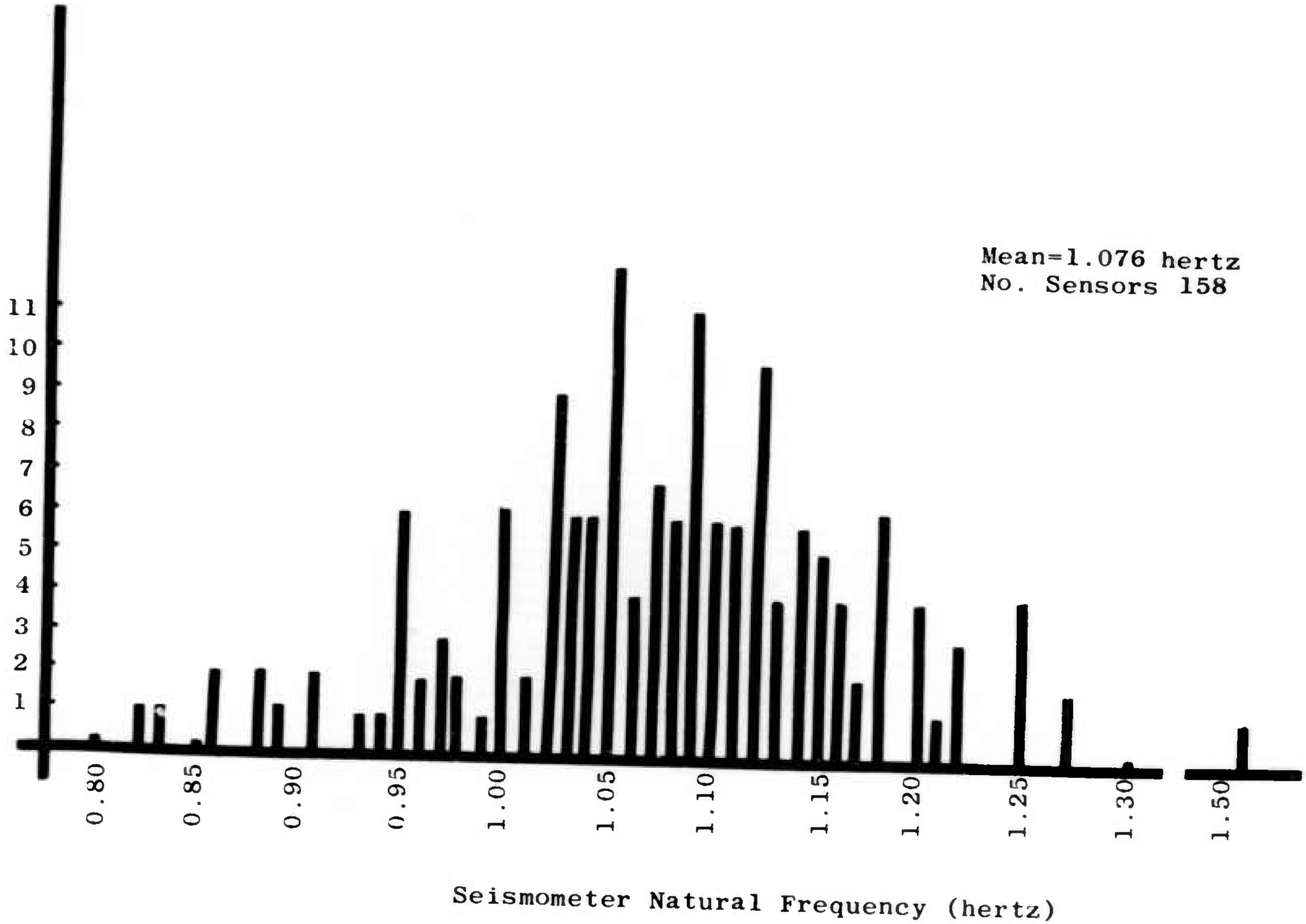


Figure 4.9 SP Seismometer Natural Frequency Distribution, 1970-71

Figure 4.10

Seismometer Natural Frequency Status of Array

| Data Channel Number | Subarrays | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A 0 | B 1 | B 2 | B 3 | B 4 | C 1 | C 2 | C 3 | C 4 | D 1 | D 2 | D 3 | D 4 | E 1 | E 2 | E 3 | E 4 | F 1 | F 2 | F 3 | F 4 |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | W | E | E | E | E | E | E | E | E | E | | E | E | W | W | X | W | W | W | W | W |
| 3 | 0 | E | E | E | E | E | E | E | 0 | X | | E | 0 | 0 | E | X | 0 | | 0 | 0 | E |
| 4 | 0 | 0 | 0 | 0 | 0 | E | 0 | 0 | 0 | | | | | | 0 | X | 0 | | | | X |
| 5 | | 0 | | | 0 | | 0 | 0 | | | | 0 | | | | 0 | | 0 | | | 0 |
| 6 | W | E | E | E | E | E | E | E | E | E | E | E | E | W | W | 0 | W | W | W | W | W |
| 7 | E | 0 | 0 | X | X | 0 | 0 | 0 | E | E | 0 | 0 | E | E | 0 | 0 | E | E | E | E | |
| 8 | 0 | | | 0 | | 0 | 0 | 0 | 0 | | | 0 | | 0 | 0 | 0 | 0 | | 0 | 0 | |
| 9 | 0 | 0 | | | 0 | | 0 | 0 | | 0 | | | | 0 | | X | | | 0 | 0 | 0 |
| 10 | W | E | E | E | E | E | E | E | E | E | | E | E | W | W | 0 | W | W | W | W | W |
| 11 | 0 | E | E | E | E | E | E | E | 0 | X | | E | | | E | X | 0 | 0 | 0 | 0 | E |
| 12 | | 0 | X | | 0 | 0 | 0 | | E | | | 0 | 0 | 0 | | 0 | 0 | | 0 | | 0 |
| 13 | X | 0 | 0 | | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 |
| 14 | E | E | E | E | E | E | E | E | E | E | E | E | E | E | E | 0 | E | E | E | E | E |
| 15 | W | 0 | 0 | 0 | | 0 | 0 | 0 | E | E | 0 | | E | E | | 0 | E | E | E | E | 0 |
| 16 | 0 | | 0 | | 0 | | 0 | | 0 | 0 | | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | | 0 |
| 17 | 0 | 0 | 0 | 0 | | | 0 | 0 | 0 | 0 | | 0 | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18 | E | E | E | E | E | E | E | E | E | E | E | E | E | E | E | 0 | E | E | E | E | E |
| 19 | 0 | E | E | E | E | E | E | E | | 0 | E | E | | X | E | X | 0 | 0 | 0 | 0 | E |
| 20 | 0 | 0 | | | 0 | | 0 | | 0 | 0 | X | 0 | | X | 0 | 0 | 0 | X | 0 | 0 | |
| 21 | 0 | 0 | | 0 | 0 | | 0 | 0 | 0 | X | 0 | 0 | | 0 | 0 | X | 0 | 0 | 0 | | |
| 22 | 0 | 0 | | 0 | | 0 | 0 | 0 | 0 | 0 | | 0 | | 0 | 0 | 0 | 0 | | 0 | 0 | 0 |
| 23 | E | 0 | | 0 | 0 | | | X | E | E | | | E | E | | 0 | E | E | E | W | 0 |
| 24 | 0 | 0 | | X | | | 0 | X | 0 | 0 | 0 | | 0 | | | 0 | | 0 | 0 | 0 | 0 |
| 25 | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | | | 0 | | 0 | 0 | | 0 | | 0 | E | | 0 |

Legend: 0 - Natural frequency within 1 ± .1 hertz

X - Natural frequency exceeds 1 ± .1 hertz

E - Empty data channel, no sensor connected

W - Weather Instrumentation Data Channel

Blank - Natural frequency measurement data not current

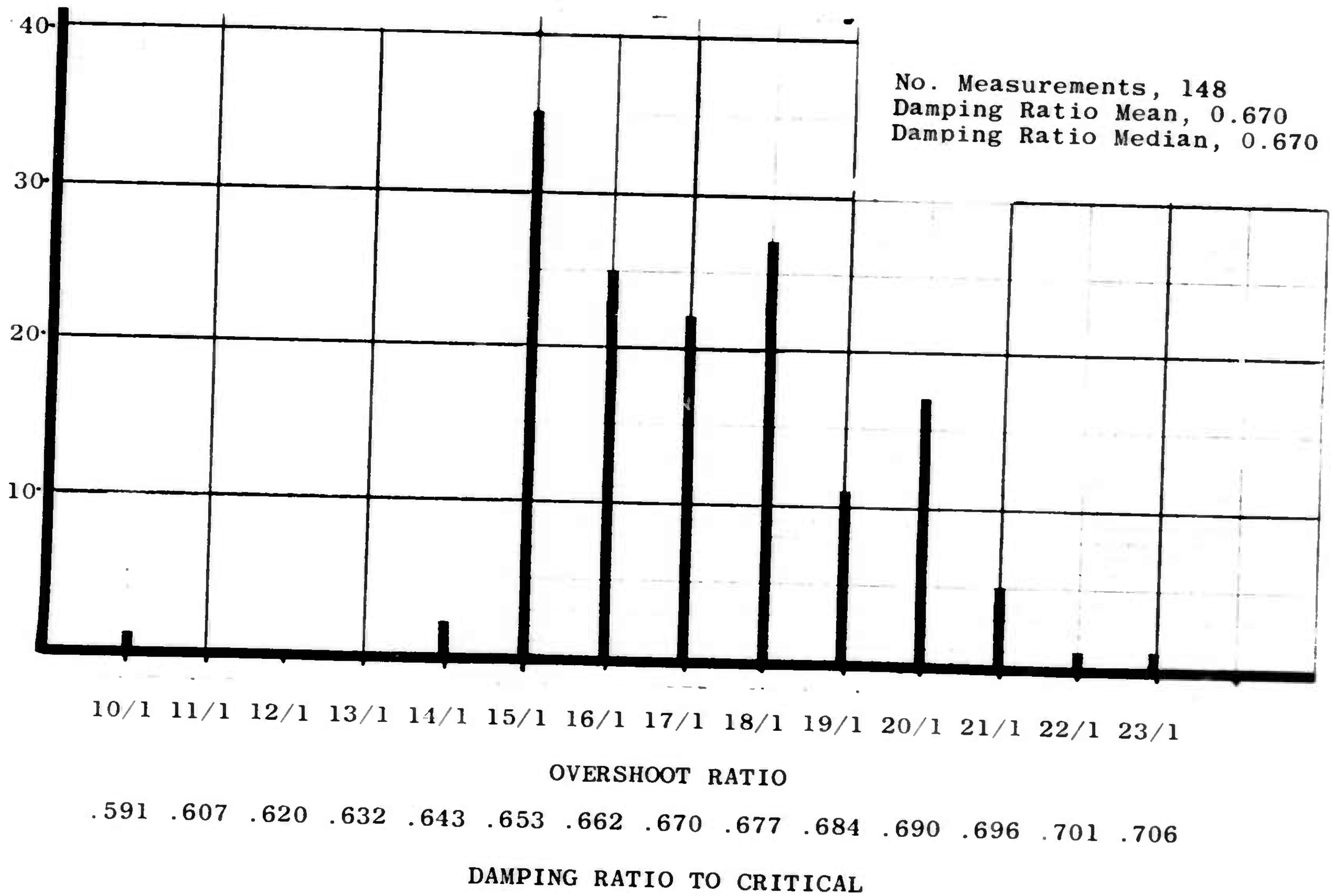


Figure 4.11 SP Seismometer Damping Ratio Distribution, 1972-73

### 4.2.3 LP Seismic Amplifier, Type II

The gain of the LP seismic amplifier at 0.04 hertz is measured remotely each week from the LDC under control of PDP-7 program TELP. The gain stability of 45 of the array's LP Type II amplifiers was determined from these gain measurement data. The standard deviation of the gain data collected between Dec 70 and Oct 72 was studied to determine the expected stability performance of the amplifier as operated in the present LASA CTH environment. The gain standard deviations show a median value of 540 and a mean value of 570. Since the seismometer data coil generator constants vary somewhat across the array, the channel amplification must vary among the amplifiers to provide the desired seismograph channel sensitivity standardization. The mean gains of the 45 amplifiers vary from 8,680 to 15,630. The individual amplifier statistics are summarized in reference 6 for the 95 week test period.

An investigation of the spurious responses in the LP system reported by Lincoln Laboratory (Ref. 7) has been conducted. A series of tests on the TI Type II amplifier have been performed at the LMC to determine if spurious low frequency output responses could be produced from high frequency signal inputs. The test set-up utilized two signal generators to simulate the effect of changes to low frequency signal input to the amplifier and the effect of combining high frequency interferring signal with the low-frequency signal. The results of the testing showed that suddenly decreasing the amplitude or increasing the frequency of the low frequency signal input did produce a spurious high level output pulse. However, introducing an increasing-amplitude high frequency signal onto a steady low-frequency signal input did not produce a very noticeable effect, viz., a slight negative shift in one cycle of the output waveform. The significance of these test results have not been determined with regard to their application to real signals applied to the LASA seismographs.

### 4.2.4 SP Calibration Oscillator

The performance characteristics of the one-hertz sinusoidal oscillator used to produce the SP array calibration signals during remote tests from the LDC have been studied. One parameter,amplitude stability over a 15-week test period, was within ± 5%. The actual measured amplitude associated with each test is reported together with the test times e.g., see Table XIII. The nominal one-hertz amplitude output from the oscilator is 20.0 Vp-p which is equivalent to 400 nm p-p. A mean amplitude of 20.68 Vp-p or 409.5 nm p-p was measured for the 21 oscillators installed in the array.

The oscillators frequencies were measured during two 30-day test periods, viz. 6 Jan - 6 Feb 72 and 13 Mar - 13 Apr 73. The frequency of each oscillator was measured

daily with a Hewlett Packard 5245L electronic counter. Telemetry command TC-14 connects the oscillator's output directly to subarray channel 30 and provides a signal for measurement that does not affect the subarray's data channels.

The nominal value for the period of the oscillator is 1 second. The results of the latest test showed the mean period of the oscillators ranged from 1.004151 seconds to 0.993725 seconds. The average mean period was 0.998573 seconds. Program TESP which is used for automatic remote calibration of the SP seismographs assumes the period of the oscillators to be 1 second. Because of the nature of these seismographs, a change in frequency creates a change in output. Because sensitivity is a function of period it is also affected by changes in frequency. In the worst case in the array the mean period differed from 1 second by 6.275 milliseconds and the largest standard deviation was less than 2.8 milliseconds. At these changes in frequency the change in seismograph output is negligable. However a slight error is introduced in the reported sensitivity. For example in the worst case the mean period is 0.993725 seconds. If a channel output is such that at the period of 0.993725 second sensitivity is 20 mV/nm, program TESP assuming the period is 1 second, will calculate the period to be 19.87 mV/nm. The introduced error is less than 1%.

The day to day variations in oscillator period are reflected in the standard deviation of the 32 samples. The range of the standard deviation is 1.194 milliseconds to 2.747 milliseconds. The period of these oscillators as indicated here vary very little from day to day and their effect on seismograph stability is negligable.

Comparing these results with the results of a similar test run in early 1972 indicate the high degree of stability exhibited by the SP calibration oscillator.

### 4.3 Facilities Not In Use

Equipment removals for shipment to NORSAR (Ref. 5) and the termination of early array study projects have left some array facilities not in use. The four LP vaults at the B-ring subarrays contain empty seismometer tanks. There are 194 well holes in array not being used (See Table XVIII). Thirteen of these have seismometers which are stuck or lost in the casing. Two of the well holes are 500 ft steel casings with 6-in ID and are located near the center holes at B1 and F3; also, two have plastic casings.

### 4.4 Seismic Studies

#### 4.4.1 Surficial Noise

Local noise sources encountered during this contract

TABLE XXVIII

ARRAY WELLHOLES NOT IN USE

| SUBARRAY | NUMBER | LOCATIONS |
|---|---|---|
| AO | 10 | 21,22,23,24,25,26,27 (Note 1), 32,34,36 |
| B1 | 10 | Near 10 (Note 2), 21 (Note 3), 22,23,24,25(3),26,31,33,35 |
| B2 | 9 | 21,22,23,24,25,26,31,33,35 |
| B3 | 9 | 21,22,23,24,25,26,31,33,35 |
| B4 | 9 | 21,22,23,24,25,26,31,33,35 |
| C1 | 8 | 21,22,23,24,25,26,33,35 |
| C2 | 9 | 21,22,23,24,25,26,31,33,35 |
| C3 | 9 | 21,22,23,24,25,26,31,33,35 |
| C4 | 10 | 21,22,23,24,25,26,32,34,36,63(3) |
| D1 | 3 | 21,22(1),32 |
| D2 | 7 | 21,22,24,25,31,33,35 |
| D3 | 9 | 21,22,23,24,25,26,31,33,35 |
| D4 | 9 | 21,22,23,24,25,26,32,34,36 |
| E1 | 9 | 21,22,23,24,25,26,32,34,36 |
| E2 | 9 | 21,22,23,24,25,26,31,33,35 |
| E3 | 18 | 21,22,23,24,25,26,31,33,35,42,44,46,51,53,55,62,64,66(4) |
| E4 | 9 | 21,22,23,24,25,26,32,34(3),35 |
| F1 | 9 | 21,22,23,24,25,26,32,34,36 |
| F2 | 10 | 21,22,23(3),34(3),25,26,32,34,36,76(3) |
| F3 | 10 | Near 10(2),21,22,23,24(3),25,26,32,34,36 |
| F4 | 9 | 21,22(3),23(3),24(3),25(3),26,31,33(3),35 |

Notes:

(1) 200-ft plastic casing
(2) 500-ft steel casing, 6-in ID
(3) Seismomter stuck in casing
(4) Hole designations used prior to E3 expansion.

have included (1) an increased train traffic near subarrays E3 and F3, (2) an increase in strip mine blasting for coal near Colstrip, Montana, also near subarray E3, and F3, (3) explosive testing near Fort Peck, Montana (near subarray F4), and oil and gas exploration drilling.

Train traffic- An estimated six or seven trains pass north of E3 each day. During the approximate 30 minutes required for each train to pass, the increase in high frequency noise level is especially apparent on E3 sensors 82 and 86.

Construction of a railroad spur line running close by subarray F3 is underway and has resulted in an increased F3 noise level during the daytime. This line will transport coal from a new open strip mine scheduled to operate near F3.

Strip mining - Information has been collected from the strip mines presently operating near the array. The blasting from these two mines located approxmately seven miles apart can be discerned to the proper mine by the delays between the arrival times at selected subarray sensors.

Explosive blasts - Recordings from a series of tests conducted near Fort Peck were studied. The availability of information, including the location, time, size, and depth of each blast has helped in the preliminary determination of travel-time curves for the local and near regional seismic activity.

Oil exploration - Twenty-seven oil and gas exploration drilling operations were reported during this contract period. Subarrays and the number of drilling locations reported near to them included: F2-11, E3-8, E4-2, B3-1, C1-1, C3-1, D3-1, D4-1, F1-1, and F3-1. The locations of the ten drilling operations reported for the final March-June period were:

SWNW Sec 32 - 1N48E approx 14 miles from Sensor F2-85.

NENE Sec 18 - 2N43E approx 11 miles from Sensor E3-84

C-SWNE Sec 11 - 6N40E approx 14 miles from Sensor E3-83

C-SW Sec 29 - 3N41E approx 14 miles from Sensor E3-75

SW Sec 19 - 8N43E approx 9 miles from Sensor D3-73, Sub D3.

NENE Sec 5 - 1N42E approx 17 miles from Sensor E3-84, Sub E3.

C-NW Sec 19 - 10N43E approx 3 miles from Sensor B3-84, Sub B3.

NW Sec 13 - 4N50E approx 11 miles from Sensor F3-81.

SW Sec 11- 5N50E approx 18 miles from Sensor F2-81

NESW Sec 16 - 2N50E approx 3/4 mile from Sensor F2-56 & 61.

### 4.4.2 Near-regional/Regional Arrivals

A LASA Near-regional/Regional Detection Bulletin is now being prepared using the array data recorded by Develocorder. Since 14 Feb 73 seventeen issues have been issued covering a time period between 2 Nov 72 and 29 Jun 73 and 760 events. Bulletin data is being used by NOAA/ERL in their Earthquake Data Report and by SAAC in their effort to develop near-regional detection and location programs as aids to identify them as false alarms on teleseismic beams.

### 4.5 Failures

The array system and equipment failures which occurred and/or were corrected are reported in this section. All the failures are classified according to the type of failure and include these five classifications:

(1) System failure- A failure resulting in zero or no system output which prevents the system or equipment assembly from performing its primary function and identified as a Type 1 failure.

(2) Mode failure- A failure resulting in a zero or no system output only during one of several different modes of operation; a Type 2 failure

(3) Limited failure- A failure resulting in a system output which is outside the allowable tolerance limits but permits degraded performance; a Type 3 failure.

(4) Latent failure- A failure which changes a system output either by an amount less than the allowable tolerance or from the nominal output when no tolerance limits have been established;

a Type 4 failure.

(5) Temporary failure- A failure produced by an operating or evnironmental stress which results in no permanent physical damage; a Type 5 failure.

The number of failures detected and corrected in each of the ten Montana array is shown in Table XXIX. The backlog of operating system failures decreased by 50% and primarily consist of defective SP sensor channels. Of the 879 failures detected the chief contributors continue, as in previous contracts, to be the SP sensor (30.5%), PDP-7 computer (25.6%), and LDC Test and Support (13.7%).

The distribution of the equipment failures which caused the system failures during the 19-month period is shown in Table XXX. A significant number of failures are reported for the RA-5 amplifier panel of the SP system, the PDP-7 tape units, and the maintenance display consoles (MDC).

Equipment failure rates and mean-time-between failures (MTBF) have been determined for the array equipment for the periods beginning May 68 and Dec 71. These figures are based on the actual number of failures; no design estimates on MTBF are available for comparison. By comparing the near-term contract rates with the long-term rates,an indication of the equipment aging may be detected by increased near-term values. Summing the rates of the ten systems produces interesting statistics, the array failure rate and the array MTBF. The array failure rates for the two periods beginning May 68 and Dec 71 are 0.06345 and 0.06311 failures per hour, respectively. The corresponding array MTBF values are 15.76 and 15.85 hours.

TABLE XXIX

LASA SYSTEM FAILURE DETECTIONS AND CORRECTIONS

December 1971 - June 1973

| SYSTEM | STARTING BACKLOG | DETECTED | CORRECTED | ENDING BACKLOG |
|---|---|---|---|---|
| SP SENSOR | 15 | 268 | 274 | 9 |
| LP SENSOR | 0 | 30 | 30 | 0 |
| METEOROLOGICAL SYSTEM | 0 | 2 | 2 | 0 |
| SEM | 0 | 91 | 91 | 0 |
| POWER SYSTEM | 0 | 29 | 29 | 0 |
| 360 COMPUTER | 0 | 45 | 45 | 0 |
| PDP-7 COMPUTER | 6 | 225 | 231 | 0 |
| LDC DIGITAL | 0 | 14 | 14 | 0 |
| LDC ANALOG | 1 | 55 | 56 | 0 |
| LDC TEST AND SUPPORT | 0 | 120 | 118 | 2 |
| TOTALS | 22 | 879 | 890 | 11 |

TABLE XXX

EQUIPMENT FAILURES

| ARRAY SYSTEM/EQUIPMENT | NUMBER OF FAILURES: TYPE OF FAILURE 1 | 2 | 3 | 4 | 5 | TOTAL |
|---|---|---|---|---|---|---|
| **Short-Period System** | | | | | | |
| Seismometer | 4 | | 55 | 16 | 1 | 76 |
| WHV Panel W/RA-5 | 24 | | 92 | 59 | 15 | 190 |
| RA-5 Power Supply | 4 | | | | | 4 |
| WHV/Cables | 2 | | | | 1 | 3 |
| CTH Junction Box (SP) | | | 3 | 3 | 1 | 7 |
| Total | 34 | 0 | 150 | 78 | 18 | 280 |
| **Long-Period System** | | | | | | |
| Vertical Seismometer/Tank | 1 | | 1 | | | 2 |
| Horizontal Seismometer/Tank | 1 | | | 2 | | 3 |
| Motor Assembly | 2 | | 1 | | 1 | 4 |
| Seismic Amplifier, Type II | 3 | | 12 | 2 | 1 | 18 |
| CTH Junction Box (LP) | | | 1 | | | 1 |
| Total | 7 | 0 | 15 | 4 | 2 | 28 |
| **Meteorological System** | | | | | | |
| Temperature Probe | | | | | 1 | 1 |
| Rain Guage Electronics Panel | 1 | | | | | 1 |
| Total | 1 | 0 | 0 | 0 | 1 | 2 |
| **Subarray Electronics Modules** | | | | | | |
| Input Drawer #1 | 1 | | 2 | 21 | 2 | 26 |
| Input Drawer #2 | 4 | | 4 | 21 | | 29 |
| Multiplexer/ADC | 2 | | 1 | | | 3 |
| Output Drawer | 6 | | 3 | | 1 | 10 |
| Control Drawer | 3 | | 11 | 1 | | 15 |
| ACC Cabinet | 3 | | | | | |
| Total | 19 | 0 | 21 | 43 | 3 | 86 |

EQUIPMENT FAILURES (CONTINUED)

| ARRAY SYSTEM/EQUIPMENT | NUMBER OF FAILURES | | | | | |
|---|---|---|---|---|---|---|
| | TYPE OF FAILURE | | | | | |
| | 1 | 2 | 3 | 4 | 5 | TOTAL |
| Power System | | | | | | |
| Control Drawer | 2 | | 8 | | | 10 |
| Inverter | 15 | | 2 | 2 | | 19 |
| Total | 17 | 0 | 10 | 2 | 0 | 29 |
| 360 System | | | | | | |
| CPU 2044 | 1 | | | | 1 | 2 |
| Typewriter 1052 | 9 | | 1 | 1 | 1 | 12 |
| Data Adapter 1827 | 2 | | | | | 2 |
| Data Adapter 2701 | 3 | | | | | 3 |
| Total | 15 | 0 | 1 | 1 | 2 | 19 |
| PDP-7 System | | | | | | |
| Computer | 6 | | 10 | | 8 | 24 |
| Teletypewriter KSR-35 | 3 | 1 | 4 | 2 | 2 | 12 |
| Card Reader | 4 | | 8 | | 3 | 15 |
| Tape Unit #19 | 6 | | 14 | | 2 | 22 |
| Tape Unit #32 | 13 | | 38 | | 6 | 57 |
| Tape Unit #33 | 19 | | 31 | | 4 | 54 |
| Tape Unit #22 | 12 | | 28 | | 4 | 44 |
| Incremental Recorder | | | | | 2 | 2 |
| Total | 63 | 1 | 133 | 2 | 31 | 230 |
| Digital System | | | | | | |
| Timing System #1 | 2 | | 4 | | | 6 |
| Timing System #2 | 1 | | 3 | | | 4 |
| Power System | 1 | | | | | 1 |
| PLINS | 1 | | | | | 1 |
| MINS | 1 | | 1 | | | 2 |
| Total | 6 | 0 | 8 | 0 | 0 | 14 |

EQUIPMENT FAILURES (CONCLUDED)

| ARRAY SYSTEM/EQUIPMENT | NUMBER OF FAILURES | | | | | |
|---|---|---|---|---|---|---|
| | TYPE OF FAILURE | | | | | |
| | 1 | 2 | 3 | 4 | 5 | TOTAL |
| Analog System | | | | | | |
| D/A Patch Panel Cabinet | | | 1 | | | 1 |
| FM System | 1 | | | | | 1 |
| 16 Channel Chart Recorder | | | 2 | | | 2 |
| WWV Receiver | 1 | | | | | 1 |
| Analog Timing System | | | 7 | | | 7 |
| SP Develocorder | 4 | 3 | 5 | 3 | 2 | 17 |
| LP Develocorder | 4 | 5 | 8 | 2 | 4 | 23 |
| Total | 10 | 8 | 23 | 5 | 6 | 52 |
| LDC Test and Support System | | | | | | |
| MDC-1 | 2 | | 74 | 2 | 3 | 81 |
| MDC-2 | | | 44 | 1 | | 45 |
| Film Viewer | 5 | | | | | 5 |
| Copier | | | 2 | | | 2 |
| Air Conditioners | | | 1 | | | 1 |
| Tape Cleaner | | | 1 | | | 1 |
| Total | 7 | 0 | 122 | 3 | 3 | 135 |

TABLE XXXI

EQUIPMENT FAILURE RATES

| ARRAY SYSTEM/EQUIPMENT | Failures/hour | | MTBF | |
|---|---|---|---|---|
| | Since 12/71 | Since 5/68 | Since 12/71 | Since 5/68 |
| Short-Period System | .02018 | .02005 | 50 | 50 |
| Seismometer | .00548 | .00208 | 183 | 482 |
| WHV Amplifier | .01370 | .01711 | 73 | 58 |
| WHV Circuits | .00000 | .00011 | - | 9058 |
| WHV Cabling | .00022 | .00022 | 4624 | 4529 |
| CTH Circuits | .00050 | .00024 | 1982 | 4117 |
| Power Supply | .00029 | .00029 | 3468 | 3484 |
| Long-Period System | .00202 | .00445 | 495 | 225 |
| Vert. Seismometer/Tank | .00014 | .00023 | 6936 | 4442 |
| Horz. Seismometer/Tank | .00022 | .00023 | 4624 | 4442 |
| Junction Assembly | .00000 | .00062 | - | 1615 |
| Motor Assembly | .00029 | .00051 | 3468 | 1974 |
| LPV Cabling | .00000 | .00034 | - | 2961 |
| Seismic Amplifier | .00130 | .00197 | 771 | 508 |
| Power Supply | .00000 | .00011 | - | 8884 |
| CTH Circuits | .00007 | .00045 | 13872 | 2221 |
| Meteorological System | .00018 | .00022 | 6936 | 4529 |
| Wind Direction Sensor | .00000 | .00007 | - | 15096 |
| Wind Speed Sensor | .00000 | .00002 | - | 45288 |
| Temperature Sensor | .00007 | .00007 | 13872 | 15096 |
| Raingauge Electronics | .00007 | .00002 | 13872 | 45288 |
| Subarray Electronics Modules | .00620 | .00775 | 161 | 129 |
| Input Drawers | .00396 | .00340 | 252 | 294 |
| Multiplexer/ADC | .00022 | .00055 | 4624 | 1812 |
| Output Drawers | .00072 | .00077 | 1387 | 1294 |
| Control Drawers | .00108 | .00287 | 925 | 348 |
| Auxilary Conditioning | .00022 | .00013 | 4624 | 7548 |
| SEM Cabling | .00000 | .00002 | - | 45288 |
| Power System | .00209 | .00183 | 478 | 546 |
| Control Assembly | .00072 | .00075 | 1387 | 1332 |
| Inverter | .00137 | .00079 | 730 | 1258 |
| Charger | .00000 | .00018 | - | 5661 |
| Rack Cabling | .00000 | .00002 | - | 45288 |
| CTH Wiring/Breakers | .00000 | .00002 | - | 45288 |

EQUIPMENT FAILURE RATES (CONCLUDED)

| ARRAY SYSTEM/EQUIPMENT | Failures/hour | | MTBF | |
|---|---|---|---|---|
| | Since 12/71 | Since 5/68 | Since 12/71 | Since 5/68 |
| 360 Computer | .00137 | .00221 | 730 | 453 |
| CPU 2044 | .00014 | .00093 | 6936 | 1078 |
| Typewriter 1052 | .00087 | .00084 | 1156 | 1192 |
| Card Reader 2501 | .00000 | .00015 | - | 6470 |
| Data Adapter 1827 | .00014 | .00011 | 6936 | 9058 |
| Data Adapter 2701 | .00022 | .00018 | 4624 | 5661 |
| PDP-7 Computer | .01658 | .01652 | 60 | 61 |
| CPU | .00173 | .00144 | 578 | 697 |
| Teletypewriter, KSR-35 | .00865 | .00073 | 1156 | 1372 |
| Card Reader | .00108 | .00121 | 925 | 823 |
| Serial Output Unit | .00000 | .00007 | - | 15096 |
| Tape Units, 570 | .01276 | .00846 | 78 | 118 |
| Incremental Recorder | .00014 | .00038 | 6936 | 2664 |
| Digital Systems | .00101 | .00064 | 991 | 1562 |
| Timing Systems | .00072 | .00042 | 1387 | 2384 |
| PLINS | .00007 | .00009 | 13872 | 11322 |
| MINS | .00014 | .00011 | 6936 | 9058 |
| Power System | .00007 | .00002 | 13872 | 45288 |
| Analog System | .00375 | .00289 | 267 | 346 |
| D/A Converters | .00007 | .00040 | 13872 | 2516 |
| FM System | .00007 | .00013 | 13872 | 7544 |
| WWV Receiver | .00007 | .00022 | 13872 | 4526 |
| Analog Timing | .00050 | .00044 | 1982 | 2263 |
| Chart Recorder, 16-Chan. | .00014 | .00057 | 6936 | 1741 |
| Develocorders | .00288 | .00181 | 347 | 552 |
| LDC Test & Support | .00973 | .00689 | 103 | 145 |
| Maint. Display Consoles | .00908 | .00654 | 110 | 153 |
| Film Viewer | .00036 | .00027 | 2774 | 3772 |
| Microfilm Copier | .00014 | .00009 | 6939 | 11316 |
| Tape Cleaner | .00007 | .00004 | 13872 | 22632 |
| Digital Clocks | .00000 | .00004 | - | 22632 |
| Emergency Lights | .00000 | .00004 | - | 22632 |
| Blower, Compressor | .00000 | .00009 | - | 11316 |
| Air Conditioners | .00007 | .00013 | 13872 | 7544 |

## SECTION V

## IMPROVEMENTS AND MODIFICATIONS

### 5.1 Introduction

Important to the operation of the Montana LASA is the continuing incorporation of improvements and modifications into the various equipments. These improvements permit increased efficiency in the utilization, operation and maintenance of the seismic observatory's systems. The improvements are categorized into these three areas, PDP-7 programming, array equipment and data center equipment. Improvements in the PDP-7 programming result in more efficient operation and increase the data collection capability of the array performance measurement activity. Modifications to the array and data center equipment are made to reduce the need for maintenance (i.e. improve reliability), to improve data quality, or to extend the operating capability.

### 5.2 PDP-7 Programming

Further development of the PDP-7 computer's array on-line system programs and significant advances in the array off-line programs are reported for Project VT/2708. The array on-line system is built around the Multiple On-line Processing System (MOPS) and its family of patch programs. Table XXXII indicates the on-line functions and capabilities presently available with the PDP-7. The MOPS II patch programs and purpose of each one are listed in Table XXXIII.

Off-line programs support a variety of data center operations. New off-line programs developed during this contract are described in this section and a review of the programs currently available and in use is also included.

#### 5.2.1 Identification of LASA Seismograph System Responses Using Pseudo-random Sequences

A system for the measurement of the LASA seismographs amplitude vs frequency and phase vs frequency responses has been developed. Such a system is required at the LASA Data Center (LDC) to provide a more comprehensive method of determining the complete response characteristics of the seismographs for insuring proper operation of the sensors as well as detecting equipment malfunctions.

The system utilizes pseudo-random bit sequences (PRBS) to generate a broadband signal which is used as an input to the array's seismometers (Ref. 8). The PDP-7 computer program RPGONE controls the PRBS using the array's telemetry

## TABLE XXXII

## PDP-7 COMPUTER ARRAY ON-LINE OPERATIONS CAPABILITIES

| | | |
|---|---|---|
| SEISMIC DATA RECORDING | - | present formats include high-rate, low-rate, and very-low rate, other formats readily prepared. |
| SEISMIC DATA DISPLAYED | - | provides up to 30 seismograph signal outputs through the serial output unit for connection to display devices. |
| SEISMIC EVENT DETECTION | - | provides bandpass filtering of seismograph signals and a scheme of eight event detectors to decide the validity of an event. |
| ARRAY MONITOR | - | detects array telemetry command and alarm status changes and provides regular array status reports. |
| WEATHER REPORT | - | provides report of current weather conditions at the meteorological stations in the array. |
| OVERLAY-PATCH PROGRAMS | - | provides subarray calibration and testing operations, seismic data processing and supports in data processing operations simultaneously with other capabilities |
| PROGRAMMING CHANGES | - | provides means of displaying or modifying the contents of any memory location. |

TABLE XXXIII

MOPS II PATCH OVERLAY PROGRAMS AVAILABLE FOR USE ON PDP-7

| PROGRAM NAME | PURPOSE |
|---|---|
| BATCK | To check battery voltages at all subarrays |
| BEAM | To provide aligning of seismograph signals into a beam and forming of up to ten beams |
| CARD | To list cards or magnetic tapes containing card images |
| DEVCAL | To provide sinusoidal calibration from seismometer thru either Develocorder or 16-channel recorder |
| DC OFF | To check SEM dc offsets at any subarray |
| FREECK | To measure LP seismometer free periods |
| FREQ | To assist MDC operator in recording SP channel frequency response test data |
| MASPOS | To check and correct (if required) the mass positions of all LP seismometers |
| RPGONE | To send pseudo-random bit sequence (or an impulse) for controlling voltage input to SP and LP seismometers |
| STDDEV | To aid in statistical analysis of array performance data |
| TASP | To measure gain of seismic amplifier and SEM amplifier and output of SP seismometer at subarrays B1 and F3 |
| TELP | To measure the sinusoidal response of the LP system, the LP amplifier channel, and the SEM LP amplifier |
| TESP | To measure the sinusoidal response of the SP system |

system.

The seismograph responses are collected by the PDP-7 computer on high-rate formatted digital magnetic tape recordings. These recordings are then later processed with the array data off-line from the computer using the broadband analysis program, RPGTWO. This program tranforms the time series data into the frequency domain by computing the harmonic content at each sample time during the PRBS period. These harmonic components, collected from the 254 data samples, determine the amplitude and phase response of each seismograph channel. By comparing the responses from each channel to the input signal as measured from the reference channel, the seismograph parameters of gain and phase for any selected harmonic of the fundamental frequency determined from the duration of the PRBS.

### 5.2.1.1 RPGONE

Implementation of the system to identify the LASA seismograph system responses using the PRBS imput is divided into two parts, one for data collection and the other for data processing. These two parts have variations within depending upon which of the two seismograph systems are being measured, i.e., the long or short-period systems. Data Collection is performed using program RPGONE with subprogram options to operate either SPRPG or LPRPG. With SPRPG the computer controls the application of telemetry to operator-selected subarrays (or sites) for applying the on-site PRBS generator output to any of five points within the SP system. This generator produces the PRBS to develop the broad-band calibration signal. With LPRPG the computer applies telemetry to the operator-selected subarray(s) according to PRBS contained in the LPRPG program itself. The data responses are recorded on digital magnetic tapes in the same format used for normal seismic recording. SPRPG collects every data sample while LPRPG selects a sample value for recording every (t/2) seconds where (t) is the time duration of each of the 127 bit positions. Collection of these calibration data can be performed simultaneously with the on-line operating system program, MOPS; program RPGONE is an overlay or patch program.

With the PDP-7 computer operating under the control of the systems program, MOPS, the paper tape for program RPGONE (includes both SP and LP) is loaded. The typed instructions "LOADUM" and "RPG" modify the operating program system for input and set for PRBS calibrations. The system is set to run and a message is generated requesting the particular seismograph system telemetry command, and site which the operator desires to collect data from.

For the SP seismograph system there are four telemetry command calibration modes available. These commands

input the PRBS at four different points of the SP seismograph channel as follows: telemetry command 09, the seismometer calibration coil; TC-12, the SEM input circuits; TC-13, the SEM multiplexer; and TC-16 the seismic amplifier. Figure 5.1 shows the SP seismograph and input points available.

Site selection is available in several different options. Any subarray may be selected individually or any combination of sets of subarrays. When the request "ALL" is made, the subarrays are selected in these three sets: (1) AO, D1, D2, D3, D4; (2) C1, C2, C3, C4, E1, E2, E3, E4; and (3) B1, B2, B3, B4, F1, F2, F3 and F4. Each set or combination is run for approximately twelve PRBS sequences or approximately $2\frac{1}{2}$ minutes.

For the LP seismograph system there are three telemetry command PRBS calibration modes available. These, shown in Figure 5.2 are (1) at the seismometer calibration coil, TC-21; (2) at the input to the seismic amplifier, TC-23; and (3) at the input of the SEM LP channel circuitry, TC-30. Site selection for the LP seismographs is handled in the same manner as the SP system except that no telemetry calibrations are sent to the B-ring subarrays since these sites have no LP sensors.

The bit width in the LP-PRBS is variable for the LP system calibrations. Any whole number may be used to request the time duration in seconds for the bit width (t), e.g., a request of 10 makes each bit width equal to 10 seconds so that the entire 127 bit PRBS requires 1270 seconds or approximately 21 minutes to complete. The present method of data recording limits the bit width to approximately 10 to maintain a sufficient sampling rate of the data.

The recording rate is one frame for every (t/2) seconds. Since the bit width (t) for the SP seismograph calibrations is fixed at 0.1 seconds, a frame is recorded every 0.05 seconds resulting in 20 samples/second. This is the maximum recording rate since it equals the incoming data rate. Consequently, the standard high-rate data recording mode used for normal data recording is utilized. For the LP seismograph calibrations the data recording rate varies depending upon the value selected for t. The format of the data recording is the same as used with the SP except the data recording rate is slower. If t is 1, one frame every 0.5 seconds is recorded so that the sampling rate is 2 samples/second.

#### 5.2.1.2 <u>RPGTWO</u>

The purpose of the data processing program RPGTWO is to retrieve the data collected from the previous program, average it, and use the averages to compute the Fourier coefficients used to determine the signal amplitude and phase

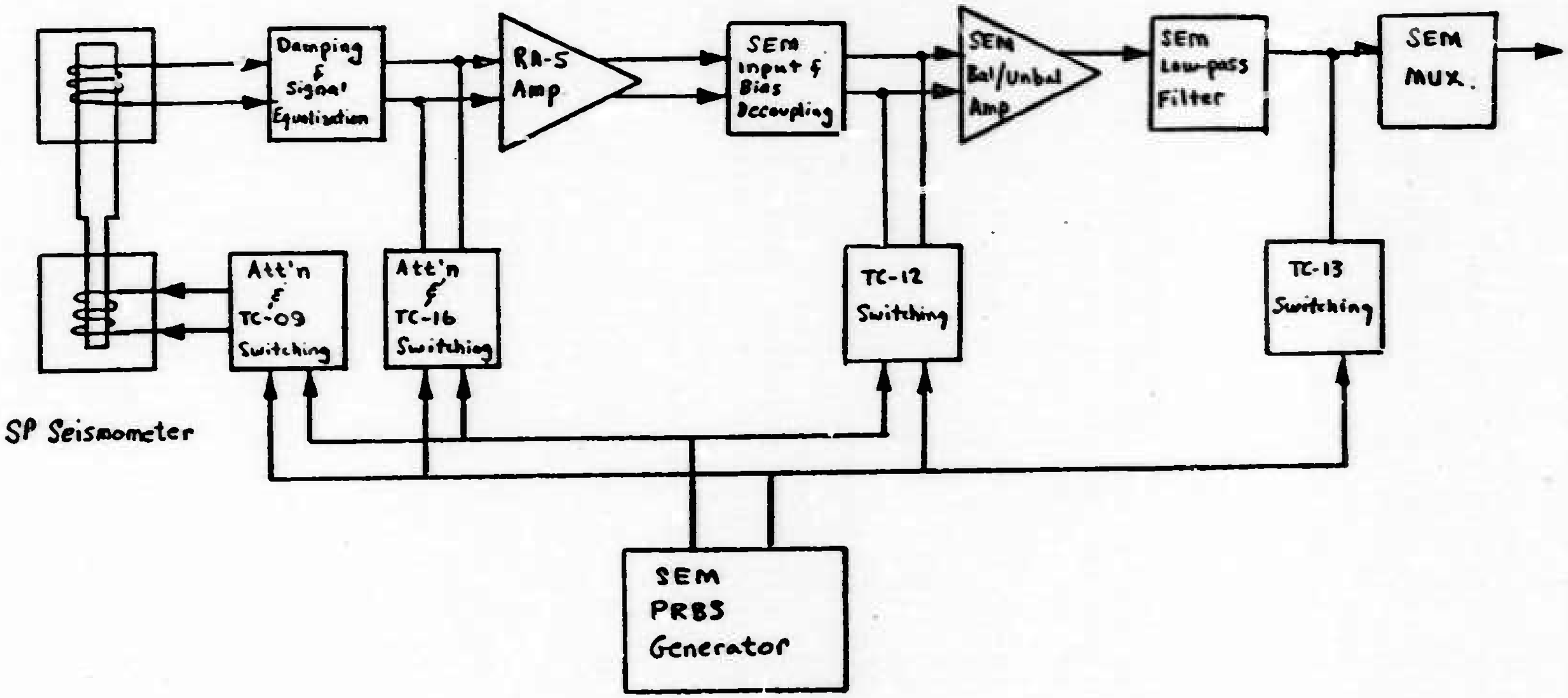


Figure 5.1 SP Seismograph PRBS Calibration Inputs

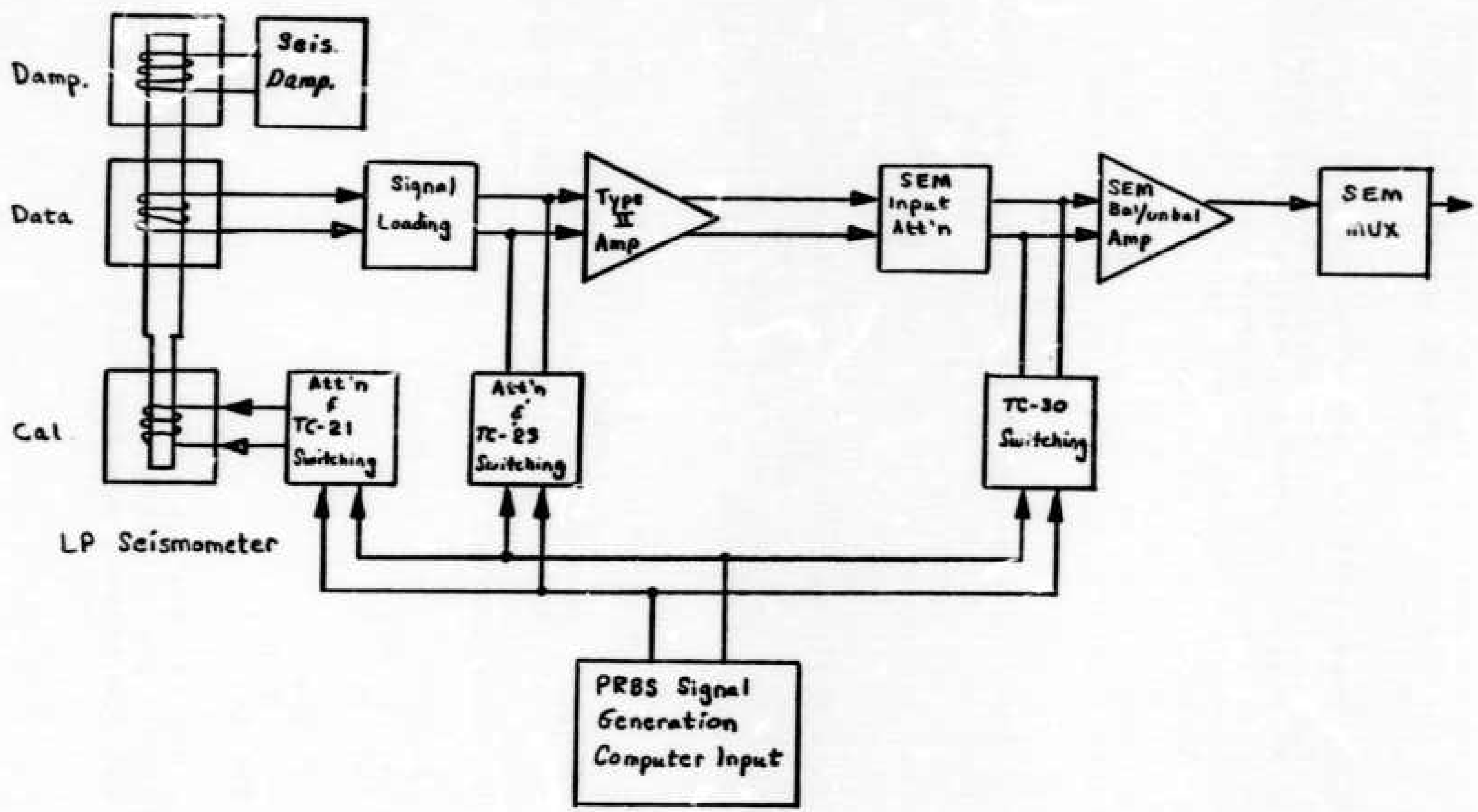


Figure 5.2 LP Seismograph PRBS Calibration Inputs

at each harmonic. Comparison of the seismograph output signal with seismograph input signal (the reference channel signal) shows the response characteristics of the seismograph channel itself. By determining the seismograph channel amplitude and phase response characteristics at each harmonic of interest, the complete seismograph channel response characteristics are determined. The gain or the ratio of the seismograph amplitude to the reference channel amplitude is also used to determine the sensitivity of the channel in terms of output voltage to equivalent earth motion input.

RPGTWO processes both the short and long-period calibration data tapes. Following the loading of the program tape, the program is started at memory location 20022 with the data tape on tape unit (logic) 7. The operator selects the subarray, system (SP or LP) and the sensor from the teletypewriter. Typing "AO BASP, ALL." will process all the SP data channels at subarray AO. If only selected data channels are desired, then "AO, BASP, 1, 3, 24, 25" might be typed where the numbers indicate the particular SP data channels from 1 to 25 desired.

For LP channel processing "BALP" replaces "BASP" in the operator request and "ALL" selects "26, 27, 28" the three LP data channels from any subarray except the B-ring; individual LP data channels may be requested if desired. When "BALP" is requested, the computer requests the minimum and maximum harmonic (N) desired. Routinely, when the bit width (t) is set at 5 in the data collection program, the minimum and maximum values of N are 8 and 38 respectively. The frequency ($f_n$) processed is determined for (N/127t) so that BALP routinely determines the seismograph responses over the range of 17 to 79 seconds/cycle.

Following the preparation of the data from a particular sensor the data is in the form of 254 values (ranging from -16383 to +16383). The first processing step is the calculation of the dc or average value of the 254 values. Since both the seismograph and reference channels are processed, averages for both are determined.

$$A_{os} = \frac{1}{254} \sum_{i=1}^{254} D_{s_i} \tag{5.1}$$

$$A_{or} = \frac{1}{254} \sum_{i=1}^{254} D_{r_i} \tag{5.2}$$

where $A_{os}$ and $A_{or}$ are the average values of the seismograph and reference channels respectively, and $D_{s_i}$ and $D_{r_i}$ are the ith data values for the seismograph and reference channel respectively.

The Fourier coefficients are determined from the following relations: For the reference channel signal,

$$B_n = \sum_{i=1}^{254} B_i \tag{5.3}$$

and

$$C_n = \sum_{i=1}^{254} C_i \tag{5.4}$$

where

$$B_i = (D_{30})_i \sin \theta\ i,n \tag{5.5}$$

$$C_i = (D_{30})_i \cos \theta\ i,n \tag{5.6}$$

For the seismograph channel,

$$E_n = \sum_{i=1}^{254} E_i \tag{5.7}$$

and

$$D_n = \sum_{i=1}^{254} D_i \tag{5.8}$$

$$E_i = (D_{ch})_i \sin \theta_{i,n} \tag{5.9}$$

where

$$D_i = (D_{ch})_i \cos \theta_{i,n} \tag{5.10}$$

The harmonic (n) and the data value index (i) are used to calculate the argument $\theta_{i,n}$ of the sine and cosine functions for the Fourier coefficients.

$$\theta_{i,n} = \frac{2n(i-127)}{127} \left(\frac{\pi}{2}\right) = (M+R) \left(\frac{\pi}{2}\right) \tag{5.11}$$

The basis for setting $\theta_{i,n}$ up like this is described in the following paragraphs and is done to simplify the calculations.

The algorithm for calculating sin $\theta$ and cos $\theta$ uses arguments of the form $X \left(\frac{\pi}{2}\right)$ $\theta$, $-1 < X < 1$. In general X exceeds

this limit. For convenience X is evaluated as the sum of two parts; a whole number (M) and a decimal fraction (R). Limiting the absolute sum of M and R to less than one limits the argument $\theta$ to a first quadrant value between $-\frac{\pi}{2}$ and $\frac{\pi}{2}$. Calculations are simplified where the angle $\theta$ is so restricted.

The algorithm is constructed as follows:

1) If $R=0$, then $M=|M|$, and the sine and cosine series approximations reduce to the special case, $\sin 0=0$ and $\cos 0=1$.
2) If $R\neq 0$ and M is positive, then the exponentials, $R^2$, $R^3$, $R^4, \ldots, R^8$ are determined for use in the sine and cosine series approximation to calculate $\sin R$ and $\cos R$.
3) If $R\neq 0$ and M is negative, then M is set to $M+4$ and a new parameter, $R'=1-R$, is determined. The exponentials $(R')^2$, $(R')^3$, $(R')^4 \ldots (R')^8$ are determined and $\sin R'$ and $\cos R'$ calculated.

The sine and cosine of the angle $\theta$ are determined from $\sin R$ and $\cos R$ depending upon the value of $|M|$ or the quadrant in which $\theta$ lies. When $|M|=0$, $\theta$ is the first quadrant and $\sin\theta = \sin R$ or $\sin R'$ and $\cos\theta = \cos R$ or $\cos R'$. R or R' is used depending upon the polarity of M as indicated above. When $|M|=1$, $\theta$ is in the second quadrant and $\sin\theta = \cos R$ and $\sin\theta = -\sin R$. When $|M|=2$, $\theta$ is in the third quadrant and $\sin\theta = -\sin R$ and $\cos\theta = -\cos R$. Finally when $|M| = 3$, $\theta$ is in the fourth quadrant and $\sin\theta = -\cos R$ and $\cos\theta=\sin R$.

Following the calculation the sine $\theta$ and cosine $\theta$ for a particular value of (i) and (n) $B_i$ and $E_i$ are calculated by multiplying sin $\theta$ by the ith data value from the seismograph and reference data values respectively. $C_i$ and $D_i$ are calculated similarly by using cos $\theta$ instead of sin $\theta$. The index (i) increased from 1 to 254 before the harmonic (n) is incremented. For a particular harmonic (n) the values for each of the four parameters, $B_n$ $C_n$ $E_n$ and $D_n$ are formed by the summation of the 254 individual (i) coefficients.

The square of the signal amplitudes are next calculated as follows:

For the reference channel,

$$(A_R)_n^2 = (B_n^2 = C_n^2) \tag{5.12}$$

and for the seismograph channel

$$(A_S)_n^2 = (E_n^2 + D_n^2) \tag{5.13}$$

The signal phases are also determined from the Fourier coefficients. The relationship between the signs of the Fourier coefficients determine in which quadrant the signal phase lies. This relationship is shown below:

| Quadrant of Signal Phase | | Sine Coefficient + | Sine Coefficient - |
|---|---|---|---|
| Cos Coefficient | + | 1st | 2nd |
| | - | 4th | 3rd |

In the first and third quadrants, a ratios are formed of the Fourier coefficients as follows:

$$R_R = \frac{C_n}{B_n} \text{ for the reference channel signal} \tag{5.14}$$

$$R_S = \frac{D_n}{E_n} \text{ for the seismograph channel signal} \tag{5.15}$$

In the second and fourth quadrants, the ratios are inverted so that

$$R_R = \frac{B_n}{C_n} \tag{5.16}$$

$$\text{and} \quad R_S = \frac{E_n}{D_n} \tag{5.17}$$

The phase is calculated from this relation

$$\text{Phase} = \text{arc tan } R_0$$

$$\text{where} \quad R_0 = \frac{R_m}{R_p} = \frac{R-1}{R+1} \tag{5.18}$$

For the reference channel $R=R_R$ and for the seismograph channel $R=R_S$. The phase ($\psi$) in radians is determined by the series approximation, so that

$$\psi = \frac{\pi}{4} + C_1 R_0 + C_3 (R_0)^3 + C_5 (R_0)^5 \tag{5.19}$$

where $\frac{\pi}{4} = 0.78540$

$C_1 = 0.99535$

$C_3 = 0.28868$

$C_5 = 0.07933$

After the signal amplitude and phase of both the input and output signals from the seismograph channel, the characteristic response of the gain and phase shift channel, itself, at each harmonic (n) is determined from

$$(\text{Gain})_n = \frac{\text{channel output}}{\text{channel input}} = \frac{(A_S)_n}{(A_R)_n} \tag{5.20}$$

$$(\text{Phase})_n = (\text{Phase})_R - (\text{Phase})_S = (\psi)_R - (\psi)_S \tag{5.21}$$

The gain of the seismograph channel is generally measured by dB referenced to the input signal. The voltage gain in dB is calculated from

$$[(G)_n]_{dB} = 20 \log G_n \tag{5.22}$$

In order to solve this logarithmic expression, the calculation is set up to utilize a series approximation for the solution.

$$\text{Let} \quad (R_G)_n = \left(\frac{A_S}{A_R}\right) \tag{5.23}$$

$$\text{and} \quad (R_M)_n = (R_G - \sqrt{10})$$

$$\text{and} \quad (R_P)_n = (R_G + \sqrt{10})$$

$$\text{and} \quad (R_G')_n = \left(\frac{R_{Mn}}{R_{Pn}}\right)$$

$$\text{now } \log (R_G')_n = 0.5 + k_1 R_G' + k_3 (R_G')^3 + k_5 (R_G')^5 \tag{5.24}$$

where $k_1 = 0.86903$

$k_3 = 0.27738$

$k_5 = 0.25433$

If $R_G < 1$, then let $R_G = 10R_G$ and subtract one from and index (GRI)

$$\log (G)_n = GRI + \log (R_G')_n \tag{5.25}$$

$$(Gain)_n = 10 \log (G)_n \tag{5.26}$$

The phase shift of the seismograph channel is determined by the following procedure.

$$(\psi_c)_n = (\psi_R)_n - (\psi_S)_n \tag{5.27}$$

where $\psi_c$ is the channel phase shift in radians

$\psi_R$ is the reference signal phase shift in radians

$\psi_S$ is the seismograph output signal phase shift in radians

Now if $\psi_C$ is negative, determine $\psi_C + \pi$ and if $(\psi_C + \pi)$ is negative, let $\psi_C = (\psi_C) + 2\pi$, otherwise $\psi_C = \psi_C$. If $\psi_C$ is positive, determine $\psi_C - \pi$ and if $(\psi_C - \pi)$ is positive let $\psi_C = (\psi_C) - 2\pi$, otherwise $\psi_C = \psi_C$. The phase shift $(\psi_C)$ is converted from radians into degrees by multiplying by 57.29578.

The seismograph channel sensitivity (S) is determined from

$$S = \frac{4\pi^2 MA}{G_C\ iT^2} \tag{5.28}$$

where S is the sensitivity in $\frac{V}{m}$,

M is the seismometers moving mass in kg

A is the channel output in V

$G_C$ is the seismometers calibration motor constant in N/A or $kg.s^2/mA$

i is the current into the seismometer's calibration coil in A

T is the period of the calibration signal in s

The constants for the LASA short and long-period seismograph are tabulated below:

| | SP | LP |
|---|---|---|
| M, kg | .825±.012 | 10 |
| $G_C$, N/A | .0326 | .028 |
| i, A | $4x10^{-5}x(A_{30})$ | $4.5x10^{-5}(A_{30})$ |
| T, s | $\frac{12.7}{N}$ | $\frac{127(t)}{N}$ |

where t is the time duration of each of the PRBS bit positions.

Using these channel constants in equation (3.28) and solving for S gives:

for SP, $S=0.15485\ (N^2)\ \left(\frac{ASN}{ARN}\right)^{\frac{1}{2}}$ mV/nm

for LP, $S=19.425\ (N^2)\ \left(\frac{ASN}{ARN}\right)^{\frac{1}{2}}$ mV/$\mu$m

where N is the harmonic number,

$A_{30}$ is the signal amplitude output from the reference channel in V.

$ARN = (A_{30})^2$

$ASN = (A_{ch})^2$

### 5.2.2 Program MOPS II

Programming changes have been made to the PDP-7's Multiple-On-Line-Processing System (MOPS) to improve the efficiency of the on-line system operation (Ref.9). These changes to the original MOPS (Ref. 10) were made primarily to increase the core memory available for the patch overlay programs used for semi-automatic array maintenance and monitoring. In the preparation of the new version certain other features were added to improve the overall system operation.

To provide increased core for the patch program: (1) the lower memory input/output buffers were realigned, (2) the on-line beam former was removed, (3) the core requirement for the on-line event detector was reduced, and (4) the interrupt answering program was rewritten. Other changes include: (1) improvement to the array monitoring output format, (2) addition of a third tape unit to the cyclic recording sequence during high-rate, back-up recording, (3) addition of a magnetic tape header check to prevent recording over a tape less than 30 days old, (4) rearrangement of the hourly weather output format to agree with the geometric configuration of the array and the calculation of a wind gust statistic, (5) incorporation of a keyboard priority to permit ready access by the operator to the program from the teletypewriter, (6) rearrangement of the on-line event detector output format to conserve paper, (7) addition of a tape edit process for recording onto a single tape the low-rate formatted data collected during the day from all event detector declared events, and (8) preparation of new low-rate and very-low-rate recording formats.

### 5.2.3 Program TESP

Program TESP (Ref. 2) had the following changes made to improve its usefullness in testing the array's SP seismographs:

(1) comparison of the positive and negative portions of each cycle of the calibration responses to determine distortion and offset of the seismograph output was changed from a comparison of areas to a comparison of peak values,

(2) capability to select subarrays individually instead of the entire array for computer controlled (TESP) calibrations was added for ease and efficiency of performing special tests,

(3) listing of all sensors with amplitude responses outside the ± 15% tolerance at the end of the TESP printout was added to aid in identifying defective channels, and

(4) format changes to the weather information prints were made to provide an indication of the temperature and wind conditions present during the TESP calibration.

### 5.2.4 Program TELP

Program TELP (Ref. 2) was made more valuable by the following improvements:

(1) determination of the sinusoidal peak-to-peak values was changed to detect and read actual peak levels instead a measurement based on area under the waveshape to improve the accuracy of the program,

(2) the multiplication constant used in calculating the sensitivity of the C2 LP seismographs was changed to correct an error in an earlier derviation, and

(3) the comparison of the positive and negative peaks to determine signal distortion and offset was added to the LP program.

### 5.2.5 Program TASP

Program TASP (Ref. 11) written to aid in the RA-5 amplifier gain analysis at subarrays B1 and F3 required one change to improve the method of detecting the durations the telemetry commands were inserted. Accuracy of the amplifier gain calculation required an exact count of the number of sinusoidal cycles applied at the input to RA-5 amplifier (TC-15) and at the input to the instrumentation after the RA-5 (TC-08); fifty zero crossings of the sinusoid are used.

### 5.2.6 Summary of Off-line Programs

During periods in which the PDP-7 computer is not required for seismic data recording, the computer is used for other data processing functions to support the array operation. These functions,not previously discussed, include: seismic data processing, equipment maintenance statistics, operations statistics, data handling activities, and program development Table XXXIV summarizes the most frequently off-line programs available at the LDC.

Two programs are used for seismic data processing, MANBUL and FILTER/PLOT. Program MANBUL, using the event delay times on punched cards, calculates the event information, e.g. velocity, arrival time and azimuth from LAO, epicenter location, distance, origin time, etc. An analog output from the computer's serial output unit (SOU) to a chart recorder

TABLE XXXIV

PDP-7 COMPUTER ARRAY OFF-LINE PROGRAMS

| PROGRAM | PURPOSE |
|---|---|
| MANBUL | To calculate seismic event information using event delay times |
| FILTER/PLOT | To filter seismic data and prepare it for display |
| RPGTWO | To calculate the gain, phase, and sensitivity of seismographs from PRBS calibration data |
| WOSR | To provide a data base for preserving the array work history and a ready means of retrieving work summary reports |
| LIST LOG | To list punch cards in computer use log format |
| COMPUTER USE LOG | To compute usage statistics |
| STACKER-EDITOR | To stack, delete, insert, or change data on magnetic tape |
| DUPE/VERIFY | To duplicate and/or verify the seismic data recording on magnetic tape |
| CARD-TAPE-LIST | To list card or paper tape data on the tele-printer or to transfer card data to paper tape |
| MAG TAPE CHECKER | To test suspected faulty magnetic tapes prior to use |
| MASTER TAPE DUPLICATOR | To duplicate and verify master paper tape programs |
| DUMP CORE ON MAG TAPE | To transfer contents of core memory onto magnetic tape |
| FLAP | To produce assembly listings and binary object paper tapes from source programs |

is also available. The FILTER/PLOT program allows the computer to accept seismograph data from magnetic tapes (both high and low rates), filter the data using either a Butterworth or a notch filter, and assemble the results through the SOU.

The array maintenance actions as reported by the work orders are coded and inputed to the computer by punched cards using the Work Order Search/Retrieval (WOSR) program to update the current WOSR magnetic tape. In the "questions" mode the WOSR program responds to a sequence of inquires into the nature and specifics of the completed array maintenance actions.

The LDC computers usage statistics are prepared using two programs, LIST LOG and Computer Use Log. LIST LOG provides listing of the punched card inputs to verify with the computer operations logs. The usage statistics are calculated using the Computer Use Log program and the punched cards covering the period of interest. Array operations statistics are determined using the Standard Deviation program which calculates the useful statistical parameters of a data set.

Data handling and transfer between the computer's input/output equipment is accomplished by several programs. The Stacker-Editor is a multi-functional program which permits stacking of information on magnetic tape from either a one or two card per line format. The program input may be from cards or a previously recorded magnetic tape. Information may be updated by use of deletion, insertion, or changing of previously recorded data. Other programs in use include: DUPE and VERIFY, CARD-TAPE-LIST, MAG TAPE CHECKER, MASTER TAPE DUPLICATOR, and DUMP CORE ON MAG TAPE.

Programming of the PPP-7 computer is usually done in assembly language using program FLAP (Fleck's Language Assembler Program) developed by MIT Lincoln Laboratory.

## 5.3 Data Center Equipment

Installation of the X-Y Plotter was the major improvement made to the data center equipment. A description of the installation and the computer interfacing is presented in this paragraph.

### 5.3.1 X-Y Plotter Installation

A used Moseley Model 135 X-Y Plotter was obtained from the government for installation at the LDC. The plotter, mounted on a sliding shelf below the incremental recorder, becomes a part of the data center's analog system. Interfacing this unit to the PDP-7 computer involved the use of two of LDC D/A converter channels and spare DEC Flip Chip Modules.

The X-Y Plotter interface accomodates three logic functions, viz., (1) conversion of computer's digital data to analog to enable proper movement of the writing pen in both coordinates, (2) program controlled gating of both the X and Y data flow, and (3) computer controlled raising and lowering of the plotter pen. The desired X and Y words are loaded sequentially into the PDP-7 accumulator. Eight of the bits (9-16) are hard-wired to DEC-to-IC logic cards in the Timing System (No. 2) cabinet. The IC level digital pulses are then applied to a pair of modified Parallel/Serial Shift Registers in D/A converter cabinet (No. 4).

An IOT generated by the PDP-7 permits the shift register parallel output pulses to enter the regular D/A circuitry of channels 73 (X) and 74 (Y). The analog outputs of these two channels are applied to the X-Y Plotter.

The control of the plotter pen is accomplished by two IOTs. One allows the pen to be lowered to trace the analog input and the other lifts the pen at the end of the desired programmed plotting sequence. Loading the PDP-7 accumulator with zeroes and transferring them to the X-Y Plotter cause a reset condition in the D/A registers which returns the raised pen to the zero position.

## 5.4 Array Equipment

Improvements and changes made to the subarray equipment include: (1) installation of the SP channel CTH gain controls, (2) modification of the SEM control drawer to provide a step function input to the LP system, and (3) removal of the array's microbarograph equipment. These accomplishments are summarized in the following paragraphs.

### 5.4.1 SP Channel CTH Gain Control

Installation of a gain control for each short-period sensor channel in the CTH was completed. This modification, designated P-82, allows periodic adjustment of all sensor channels thereby reducing somewhat the variations in the array mean sensitivity caused by seasonal temperature changes. Previously channel gain adjustments had to be made at each individual WHV. During the winter months travel to most WHV locations is not practical while most of the CTH locations are accessible.

A detailed description of the modification is presented in Reference 11 and the installation schedule for the 21 subarrays indicated in Reference 12. Figure 5.3 shows the SP seismograph analog signal path with the modification installed.

### 5.4.2 LP Step Function Input Connections

A remote telemetry controlled step input to the

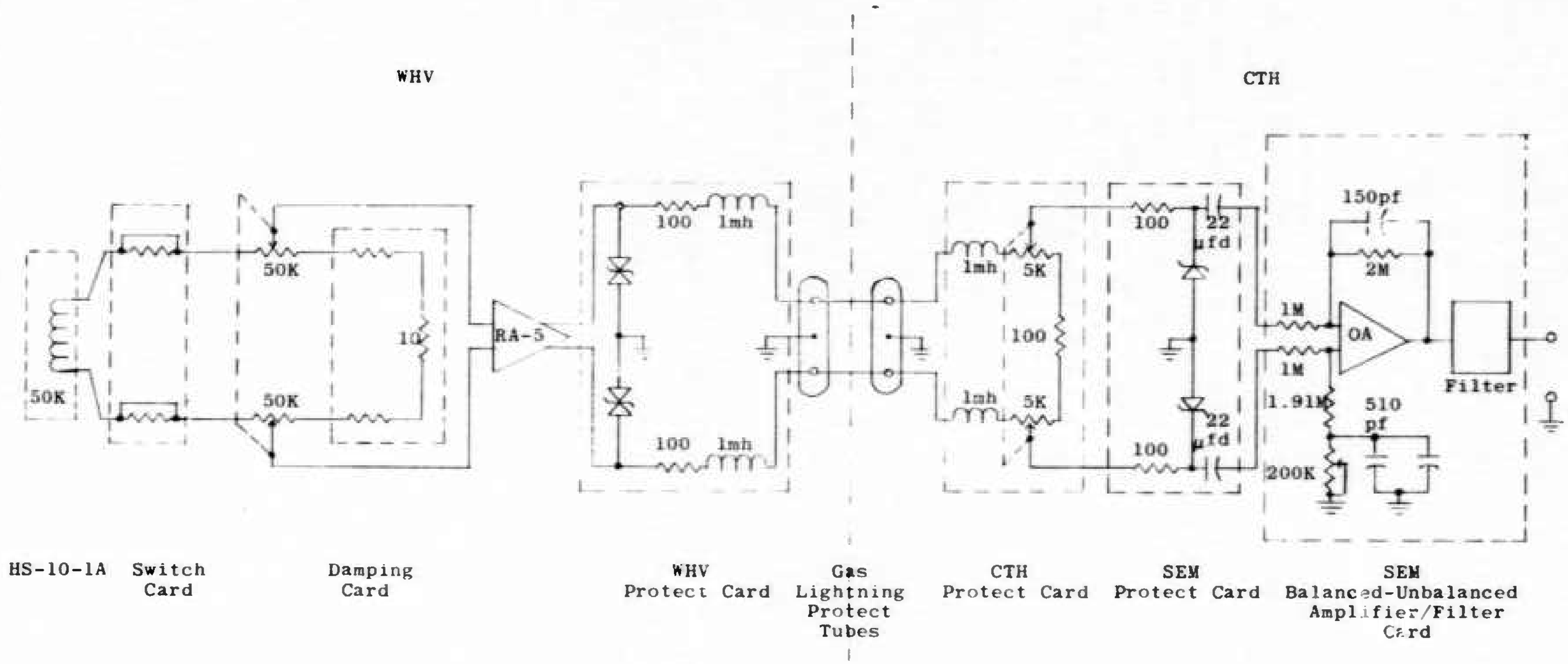


Figure 5.3 Modified SP Seismograph Analog Signal Path

long-period seismograph system allowing the PRBS calibrations was provided by a minor modification to the SEM control drawer. Installation of two short jumper wires on PC board connector A6 during the P-82 modification (see para. 5.4.1) increased the capability of the SEM calibration function. The SEM calibration signal flow is diagrammed in Figure 5.4.

5.4.3 Microbarograph Removal

The microbarograph array was eliminated by the removal of all sensors and instrumentation. The ESYS microbarographs installed at the thirteen subarrays in the B-, C-, D-rings and AO and the LTV-6 microbarographs installed at the eight subarrays in the E-and F-rings and AO were removed and shipped to other locations at the direction of the VSC Project Officer. The schedule of the sensor removals and data disconnections is reported in Reference 8. Recording of the microbarograph data at the LDC in the very-low-rate recording format was discontinued at 1939 GMT on 24 Mar 72.

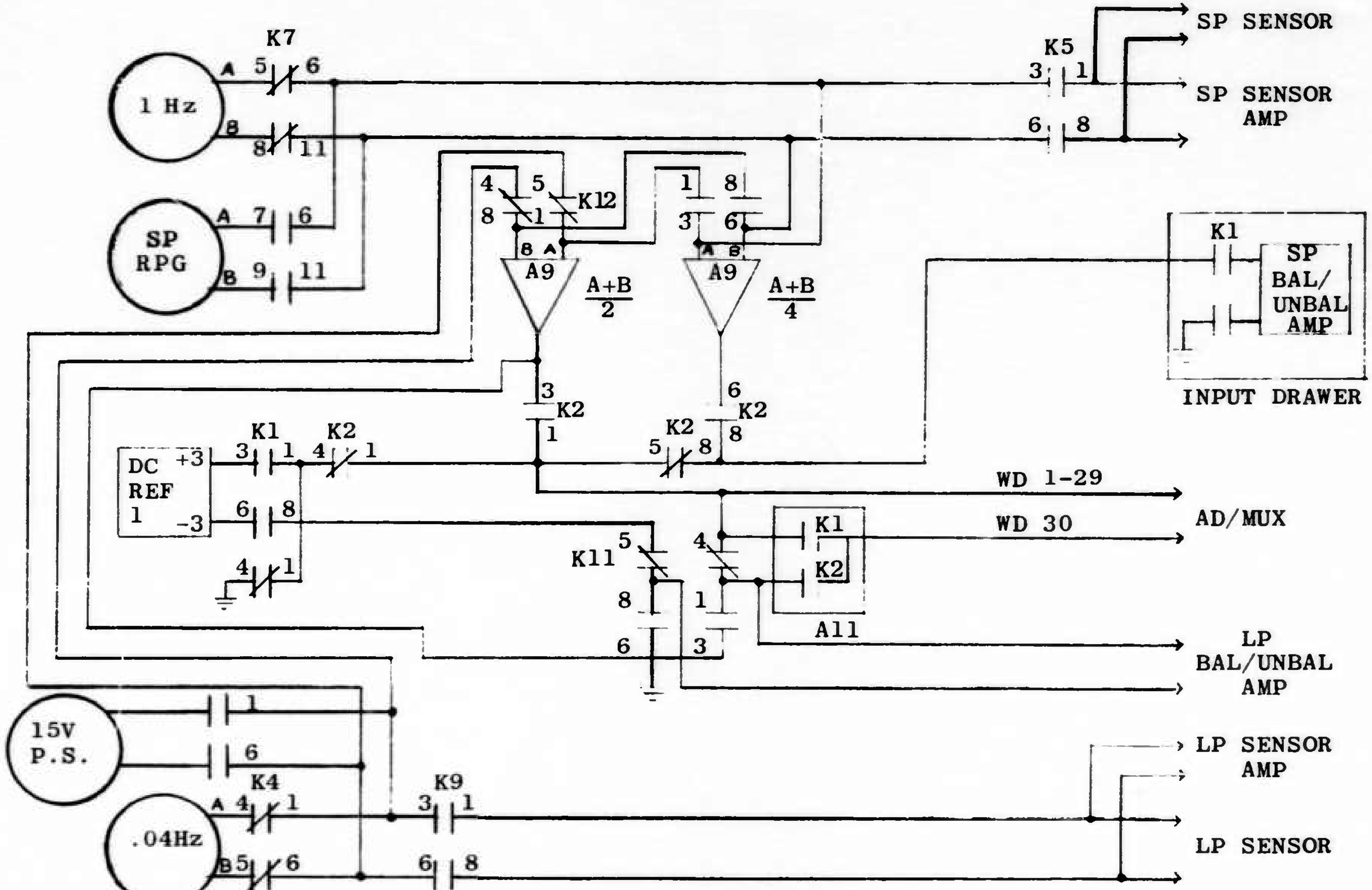


Figure 5.4 SEM Calibration Signal Flow

## SECTION VI

## MAINTENANCE

### 6.1 General

Maintenance activity at LASA includes correction of failures, preventive maintenance, modifications, special tests required for evaluations or quality control activities, facility and access maintenance, improvements, and vehicle maintenance. LASA maintenance activity is divided into three different categories: Data Center (LDC), Maintenance Center (LMC) and Facilities Support. The LDC in Billings covers the following five systems: the IBM 360/44 computer, the DEC PDP-7 computer, LDC Digital, LDC Analog, and the LDC Test and Support. The LMC located in Miles City maintains all array equipment systems which are comprised of SP Sensor, LP Sensor, Meteorological, SEM, and Power. Facilities Support provides maintenance of buildings, vehicles, land leases, and array facilities such as cable trenches, access trails, fences, WHV sites, and CTH sites.

#### 6.1.1 Philosophy

During December through March, weather and road conditions usually limit travel to the SP sensor locations. Throughout these months the LMC maintenance effort is concentrated on shop repair and testing of seismometers, seismic amplifiers, and printed circuit cards. Trips to the array are made only for emergency repairs or when weather and road conditions permit. Preventive maintenance is limited to inspections, checking of power and alarm systems, and system adjustments that can be accomplished at the CTH. When the spring run-off and rains occur, CTH water alarms are monitored to indicate water on the vault floors, and emergency trips, if necessary, are made to pump and mop out the water to protect the equipment.

Except for isolated storms the weather conditions during April through November permit unrestricted travel in the array. The SP sensor rehabilitation, installation of modifications, and special testing requiring travel to the sensor WHV are given prime attention. Shop work at the LMC is limited to preparing RA-5 amplifiers and HS-10-1A seismometers for sensor replacements. Other LMC work, such as printed circuit card repairs, are deferred until inclement weather makes array travel difficult. Preventive maintenance during this period includes, clean-up of the CTH and area in the spring and fall, weather station calibration in the summer, and battery, fan, and filter servicing in the fall.

Weather and travel do not affect the LDC maintenance



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program providing a more constant work load based on a preventive maintenance schedule. Lack of equipment redundancy requires the timely repair of all failures.

6.1.2 Summary

Array equipment maintenance completed at LMC included SP rehabilitation at 18 subarrays, installation of SP Channel CTH Gain Control modification at all subarrays, removal of all microbarograph equipment, preventive maintenance, repairs at selected WHV locations and LP sensor channels, and shop repair of array equipment spares. The LDC effort centered mainly on the PDP-7 system, Develocorders, and preventive maintenance.

Table XXXV summarizes the number of equipment (LASA) and facility (Utility) work order actions for the period December 1971 - June 1973. The 2,180 completed work orders represented 2,904 separate maintenance actions by technical personnel since several repair actions may be listed on a work order in clearing a particular discrepancy. Work orders are used to document all LASA maintenance activities. Table XXXVI provides a work order summary for the final period of contract, March-June 1973.

6.2 Data Center

6.2.1 System 360

The IBM 360/44 system operated for one six-month period March-August 1972, during the contract without any failures. Out of eight system failures during this contract, five were caused by the 1052 typewriter. These mechanical failures are expected since the typewriter operates regularly 24-hours a day. The 1052 failures were as follows:

1. Broken rotate tapes and a defective carriage return cord.

2. A broken wire on the carriage return contacts. This wire carries the voltage for all contacts used to signal the CPU on typewriter functions. The wire broke due to the normal vibration of the unit.

3. The cycle clutch jammed and ruined the drive belt. Cleaning, repacking the cycle clutch, a new drive belt, and mechanical re-alignment restored the units operation.

4. Broken tab and carriage return cords.

5. Noisy operation in spite of preventive maintenance required complete cleaning and oiling of the

TABLE XXXV

WORK ORDER SUMMARY

DECEMBER 1971 - JUNE 1973

| WORK ORDER TYPE | BACKLOG START OF CTR | INITIATED | COMPLETED | BACKLOG END OF QTR |
|---|---|---|---|---|
| LASA: | | | | |
| System - A | 27 | 1385 | 1383 | 29 |
| Subassembly - B | 40 | 229 | 244 | 25 |
| Component - C | 127 | 152 | 244 | 35 |
| Total | 194 | 1766 | 1871 | 89 |
| Utility: | | | | |
| Cable trench & trail inspection | 0 | 50 | 50 | 0 |
| Cable trench backfill | 1 | 6 | 7 | 0 |
| WHV sites landscaped | 0 | 91 | 91 | 0 |
| Marker posts & or WHV covers replaced | 0 | 36 | 36 | 0 |
| CTH maintenance | 7 | 75 | 64 | 18 |
| Vehicle maint-nance and in-spection | 3 | 43 | 46 | 0 |
| Fence inspections | 4 | 14 | 13 | 5 |
| Trail repairs | 2 | 0 | 2 | 0 |
| Total | 17 | 315 | 309 | 23 |
| WORK ORDER TOTALS | 211 | 2081 | 2180 | 112 |

TABLE XXXVI

WORK ORDER SUMMARY

MARCH 1973 - JUNE 1973

| WORK ORDER TYPE | BACKLOG START OF QTR | INITIATED | COMPLETED | BACKLOG END OF QTR |
|---|---|---|---|---|
| LASA: | | | | |
| System - A | 17 | 258 | 246 | 29 |
| Subassembly - B | 12 | 49 | 36 | 25 |
| Component - C | 24 | 19 | 8 | 35 |
| Total | 53 | 326 | 294 | 89 |
| Utility: | | | | |
| Cable trench & trail inspection | 5 | 15 | 20 | 0 |
| Cable trench backfill | 0 | 4 | 4 | 0 |
| WHV sites landscaped | 0 | 38 | 38 | 0 |
| Marker posts & or WHV covers replaced | 1 | 6 | 7 | 0 |
| CTH maintenance | 0 | 26 | 8 | 18 |
| Vehicle maintenance and inspection | 0 | 4 | 4 | 0 |
| Fence inspections | 5 | 1 | 1 | 5 |
| Trail repairs | 0 | 0 | 0 | 0 |
| Total | 11 | 94 | 82 | 23 |
| WORK ORDER TOTALS | 64 | 420 | 376 | 112 |

main shaft bushings. Compressed packing in oil holes was not allowing flow of lubrication to bushings. The other three failures were as follows:

1. Failure of an 1827 Data Adapter logic card (A33H) prevented its remote operation.

2. An intermittant bit in the CPU storage register required replacement of the logic card installed in location A-A3J4.

3. Failure of the 2701 unit prevented transmittal of data to SAAC. The problem was corrected by replacement of the logic card in location B2D4. The faulty card caused a false error to be detected in the CRC register preventing transmission.

All scheduled preventive maintenance was completed on the system during the contract.

### 6.2.2 System PDP-7

Within this system the greatest concern during this contract was the TD-570 tape units. The units required frequent maintenance due to mechanical breakdowns. Mechanical wear on all surfaces in contact with the tape required replacement, with new or salvaged parts, e.g., such main items as capstan assemblies, arm and shaft assemblies, block and solar cell assemblies, and read-write head assemblies. Although the units are repairable the main problem is availability of replacement parts. Due to the age of the units (8 years) many of the parts are no longer stocked or manufactured and procurement requires the supplier to re-tool and manufacture the parts. This naturally increases their cost and delivery time. Suppliers have been increasingly non-responsive to inquiries.

The tape units were maintained to operate within factory specifications due mainly to the stock of parts that were on hand and five TD-570 units and compressors scrapped by MIT Lincoln Laboratory and obtained by LDC for salvage parts.

The three on-line TD-570 tape units were repaired to meet all specifications utilizing parts from the five salvaged units received from MIT. All deteriorated appearance items (e.g., door glass, panels, switches, etc.) were also replaced. One of the salvaged units was placed on a limited operational basis to be used for checking out major salvaged parts, such as power supplies, printed circuit cards, compressors, etc. Some of the mechanical assemblies mentioned still show

signs of wear but the remaining salvage parts are no better. If further failures occur due to these assemblies, an on-line unit will have to be cannabilized to try to maintain at least two units operational. Only three external compressors are now operational. The old compressors have been overhauled numerous times and are beyond further repair. Internal compressors will be used with increase in operating temperature and noise level. Every effort will be made to maintain these units operational until new tape units are installed.

The only major problem encountered in the PDP-7 mainframe was a failure in the PDP-7 memory system. The memory read/write power supply failed due to an open filter capacitor which prevented operation of the system. A substitute capacitor was used to restore operation of the system until a new component was obtained and installed. The only anticipated problems with the system will be in mechanical assemblies such as the teletypewriter, switches, paper tape punch and reader, blower assemblies, and card reader. Failures have occurred with these items but to date parts have been available.

### 6.2.3 Other LDC Equipment

Both Develocorder units were overhauled after an 18 month interval since the previous overhaul. The plastic gravity feed hoses had hardened and developed leaks so overhauls will be scheduled at 12-month intervals in the future to prevent operational failures. The metal front plate and light shield partitions coming in contact with solutions were badly deteriorated by chemical action. The aluminum front plate was replaced by a locally fabricated stainless steel plate. The light shields were replaced by painted aluminum shields constructed by LDC personnel.

The deteriorating effect of Develocorder chemicals upon copper drain pipes was demonstrated shortly after the initial installation of the Develocorder rack and drain system. Replacement of the copper pipe drain system with plastic (PVC) pipe was completed. One short vertical section of copper, connecting the PVC pipe to the drain, was not replaced. Now this pipe has been completely dissolved by the long term chemical action. A replacement was fabricated using galvanized nipples and a pipe union. The life expectancy of the galvanized pipe is shorter than PVC but the pipe union will facilitate future replacements.

The 15-ton, rooftop air conditioner required repair due to a refrigerant leak and a fan belt problem. Following this repair, a study determined an efficient set-up for the computer room's environmental system. An SOP covering the operation of the system to maintain full-flow, double filtered air at 72°F with approximately 40% humidity in the computer room was prepared. Improvement has been noted by the cleanliness of the equipment and filters and reduction of failures due

to heat.

During this contract period 255 preventive maintenance routines were completed on LDC equipment.

## 6.3 Maintenance Center

The LMC maintenance efforts are divided into two activities: array tasks and shop testing and repairs.

### 6.3.1 Array Activities

During this contract 598 field trips covering 92,573 miles and 14 trips to the PMEL at Great Falls to pick up and deliver test equipment for calibration were made. There are 82 pieces of test equipment that are scheduled for calibration at the PMEL from LDC and LMC. Nine trips per year are made utilizing LMC trucks and personel to maintain this schedule.

The largest task at LMC was rehabilitation of the SP sensor channels which is a continuing program. During the contract 18 subarrays were rehabilitated plus numerous individual sensor channels. This task resulted in 117 RA-5 amplifiers replaced, 82 RA-5/panels adjusted or repaired, 44 HS-10-1A seismometers replaced, 19 HS-10-1A adjusted (rotated in the borehole for improved natural frequency), and 17 HS-10-1A seismometers tested in the borehole. A frequency response test was completed at 18 subarrays and natural frequencies measured on all seismometers at subarray E3. The seismometer cable broke while trying to remove the stuck seismometer at WHV 63 at subarray C4. Consequently, this sensor channel is no longer used. Additional seismometers having high natural frequency were found stuck in the casing and were left operating as is. These included AO-83, B2-53, E1-45, E1-65, E3-43, F1-65, and F4-51.

During this contract period 588 preventive maintenance routines were completed on equipment in the array. All subarrays were visited for preventive maintenance checks and for adjustment of the dc offset on the SEM SP input channels to within ± 5 mV.

Installation of the SP Channel CTH Gain Control Modification, P-82, was completed at all subarrays. Subarray adjustment of SP seismograph channel gain is being routinely scheduled and 40 subarray visits have been made since 29 September 1972. Two different methods of selecting channels for adjustment are being used. At subarrays D2 and D3 the all channel gains are being set to nominal levels. At the other subarrays the channel outputs are being set to limit the drift in channel gain to within a limited range over a limited time period. The results will be studied and a plan will be selected that will best utilize this modification.

The SP Channel Status of the outstanding conditions in the SP array requiring maintenance attention as of 30 June 1973 is summarized in Table XXXVII. Based on the five test criteria shown in the column headings, a total of 51 unsatisfactory conditions are reported. This shows a decrease of 74% from 194 reported at the start of the contract. Correction of unsatisfactory natural frequencies, improper one hertz calibration and broad band sensitivity responses reduced the number. However, previous status indicated only those sensors whose natural frequencies measured out-of-tolerance. Those sensors whose frequencies had not been measured since installation were considered satisfactory. Now the status report has been updated to include all sensors. To determine the natural frequency of the seismometers in which no recent tests has been made, the 1965 installation measurements were used. All with natural frequencies in excess of 1.0 ± .1 hertz are indicated as unsatisfactory and are being scheduled for testing and repair as necessary. During the next contract all 1965 installation measurements will be checked to update all data. Although 37 seismometers are listed with unsatisfactory natural frequency measurements, not all will be corrected. There are seven that are stuck in the casings and will be operated as is and four at subarray D1 are in uncased holes and can not be removed.

### 6.3.2 Shop Activities

Shop activities included amplifier, seismometer, and subassembly repairs to support the field maintenance program plus repairs of deferred work orders on power supplies, printed circuit cards, etc. In support of the maintenance program the following shop repairs and testing was required:

| | |
|---|---|
| Printed Circuit Cards | 228 |
| RA-5 Amplifiers | 131 |
| HS-10-1A Seismometers | 64 |
| Type II Amplifiers | 3 |
| SEM Drawers | 24 |
| Misc. Units | 18 |
| Total units repaired | 468 |

Some seismometers (HS-10-1A) after being overhauled in the shop were found to be out-of-tolerance in natural frequency because of a lower temperature in the casing. To eliminate this problem the seismometers are now checked and adjusted at borehole temperature utilizing the environmental chamber before sealing.

TABLE XXXVII

SP CHANNEL STATUS, 30 JUNE 1973

| SUBARRAY | CALIBRATION RESPONSE | | NATURAL FREQUENCY | | SENSITIVITY RESPONSE | | SEISMIC EVENT POLARITY | | SEISMIC EVENT AMPLITUDE | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SAT. | UNSAT. | SAT. | UNSAT. | SAT. | UNSAT. | SAT. | UNSAT. | SAT. | UNSAT. |
| AO | 17 | 0 | 15 | 1 | 16 | 0 | 17 | 0 | 17 | 0 |
| B1 | 17 | 0 | 16 | 0 | 16 | 0 | 16 | 1 | 17 | 0 |
| B2 | 17 | 0 | 15 | 1 | 16 | 0 | 17 | 0 | 17 | 0 |
| B3 | 16 | 1 | 13 | 3 | 15 | 1 | 17 | 0 | 17 | 0 |
| B4 | 17 | 0 | 16 | 0 | 16 | 0 | 17 | 0 | 17 | 0 |
| C1 | 15 | 1 | 13 | 2 | 15 | 0 | 16 | 0 | 16 | 0 |
| C2 | 17 | 0 | 16 | 0 | 15 | 1 | 17 | 0 | 17 | 0 |
| C3 | 16 | 1 | 14 | 2 | 15 | 1 | 17 | 0 | 17 | 0 |
| C4 | 16 | 0 | 15 | 0 | 14 | 1 | 16 | 0 | 16 | 0 |
| D1 | 17 | 0 | 12 | 4 | 16 | 0 | 17 | 0 | 17 | 0 |
| D2 | 20 | 1 | 18 | 2 | 20 | 0 | 21 | 0 | 21 | 0 |
| D3 | 17 | 0 | 14 | 2 | 16 | 0 | 17 | 0 | 17 | 0 |
| D4 | 17 | 0 | 13 | 3 | 16 | 0 | 17 | 0 | 17 | 0 |
| E1 | 17 | 0 | 14 | 2 | 16 | 0 | 17 | 0 | 17 | 0 |
| D2 | 16 | 1 | 15 | 1 | 15 | 1 | 17 | 0 | 17 | 0 |
| E3 | 24 | 1 | 18 | 7 | 25 | 0 | 25 | 0 | 25 | 0 |
| E4 | 17 | 0 | 15 | 1 | 16 | 0 | 17 | 0 | 17 | 0 |
| F1 | 17 | 0 | 15 | 1 | 16 | 0 | 17 | 0 | 17 | 0 |
| F2 | 16 | 0 | 15 | 0 | 14 | 1 | 16 | 0 | 16 | 0 |
| F3 | 17 | 0 | 13 | 3 | 16 | 0 | 17 | 0 | 17 | 0 |
| F4 | 16 | 1 | 14 | 2 | 16 | 0 | 17 | 0 | 17 | 0 |
| TOTAL | 359 | 7 | 309 | 37 | 340 | 6 | 365 | 1 | 366 | 0 |

A new method is being evaluated for pressure testing HS-10-1A head/cable assemblies and cases. The old method using pressurized water is adequate but if either a leak is present the seismometer, or by wicking action the cable can be damaged. The new system utilizes a modified top plate with air valve to test the case and a modified case with air valve to test the head/cable assembly. The units are pressurized with air and placed in a container of water. Air bubbles indicate leaks,and several cases have been found with minute leaks in the welds. With the old method, if a case leaked,the seismometer had be be disassembled and rechecked and any water damage repaired. A leak in the head assembly usually required installing new cable.

## 6.4 Facilities Support

Supporting the array are the facilities and vehicles necessary for the established operations. These include: (1) the buildings housing the LDC and LMC (2) the land required for the array's CTH, LPB, and WHV locations, and (3) the special trucks used for travel between the facilities.

### 6.4.1 Program Supporting Structures

The provision and maintenance of two building structures, viz., the LASA Maintenance Center (LMC) at Miles City, MT, and the LASA Data Center (LDC) at Billings, MT, was continued on a lease basis during the entire contract period. Each building with circa 6,000 sq. ft. floor space adequately accomodated all hardware, vehicles, personnel, and administrative and logistical functions.

### 6.4.2 Land Provision and Maintenance

Ninety-three (93) lease agreements were again renewed during this contract period. In general, the terms of these agreements include the use of an area 150 ft. x 150 ft. at each sensor and at each subarray central, cable right-of-way, access to these sites, the right to place and use seismic and related equipment at each site, the responsibility for maintaining surficial landowner property effected by the program such as sensor site landscaping, trails, fences and gates and the responsibility to maintain safe-guards against injury or damage to landowner property and livestock.

To maintain an effective liaison with landowners, there were 248 landowner visits within the array area. These visits were throughout the period with at least six made a month. No claims were made by landowners for damages.

The amount of land maintenance activity is indicated in the utility work order summary shown in Tables XXXV and XXXVI where a total 263 completed work orders are reported for

the contract period. Land restoration work after the spring of 1972 was necessary at four subarrays. The CTH access trail was bladed at F2. Culverts were replaced at B3 and C3; a cattle guard and several crossings were also repaired at C3. Two cable trench washouts and several creek crossings were repaired at E3. Following the light snow cover of the most recent winter very little damage was detected during the spring of 1973. Work has been completed at two subarrays. Exposed cable was covered with rock and dirt at three locations between WHVs and four washouts filled at E3. Exposed cable was covered at one location at D3.

The problem of water leakage through the cracks in certain of the CTH vault walls has apparently been solved by heavy ground surface applications of bentonite, a chemical with sealing properties. Both subarrays C3 and E3 received the bentonite treatment.

### 6.4.3 Vehicles

A fleet of four-wheel drive Ford trucks with power winches, radio telephone, spare fuel tanks and other emergency equipment was maintained at all times for the various array maintenance functions. With these vehicles all of the necessary program field related travel requirements were met. Vehicular activity during this contract period consisted of 93,000 miles safely driven in the conduct of LASA maintenance under varying conditions of roads and weather.

# SECTION VII

## ASSISTANCE PROVIDED TO OTHER AGENCIES

### 7.1 Seismic Data Laboratory (SDL)

Develocorder film recordings of selected SP array seismographs were made for SDL daily throughout the contract period. Each film covered 24 hours starting at approx. 1800 GMT. The format now in use is: F4-10(SPZ), F1-10(SPZ), F3-10(SPZ), F2-10(SPZ), AO-10(SPZ), AO-10(SPAZ), E3-10(SPZ), E3-73(SPZ), and E3-75(SPZ).

LASA Near-regional and Regional Detection Bulletins LDB 73-1 through 73-17 were distributed to SDL.

Eight VLR magnetic recordings of microbarograph and related digital data were shipped SDL.

### 7.2 National Earthquake Information Center (NEIC)

Assistance was provided to NEIC in Boulder, Colo., by aiding in the rapid location of large earthquake and the reporting of detection times of regional and near-regional events. A copy of each of the 17 near-regional detection bulletins was mailed to NEIC. The release of this data had the prior approval of our VSC project officer.

### 7.3 Weather Bureau

The Billings Weather Bureau office continued their periodic request for weather information from the array's temperature, wind direction and speed, barometic pressure, and rainfall sensors. At least three times a day a complete report of the current sensor outputs were provided to the weather bureau meteorologist by the LDC operators.

### 7.4 MIT Lincoln Laboratory

The on-line FM data link between the LDC and MIT was operated throughout the contract period. The ten array data channels now transmitted are: F1-10(SPZ), F2-10(SPZ) F3-10(SPZ), F4-10(SPZ), F4-11(LPZ), E1-10(SPZ), E2-10(SPZ), E3-10(SPZ), AO-10(SPZ), and F4-10(SPAZ).

Tests were performed to provide digital data recordings of step responses of the LP seismometers at a subarray, the PRBS responses of the SP seismometers at a subarray, and the pulse input responses from two LTV-6 microbarographs.

7.5 Tonto Forest Seismological Observatory (TFSO)

A description of the LDC Develocorder gravity flow regulated chemical distribution system was provided to TFSO. Methods employed and materials used at the LDC to insure continued operation were indicated.

A set of the SEM printed circuit cards used for the SP PRBS calibrations were provided for use at TFSO.

7.6 Visitors

Official visitors to the array since March 1973 included:

Capt. John Fergus, VSC Montana LASA project officer, inspected the array facilities udring May 15-19, 1973.

Mr. Martin Gudzin, Teledyne/Geotech, toured the array and discussed the Geotech instruments.

Mr. M. Phyl Poulson, contracts compliance specialist, conducted an EEO compliance audit.

Mr. Henry Wopperer, property administer, and Darrell Small, quality control inspector, of DCASD, Seattle, performed the annual government property survey during June 12-22, 1973.

## SECTION VIII

## DOCUMENTATION PROVIDED UNDER VT 2708

### 8.1 Technical Reports

Following the requirements of the CDRL, thirteen monthly reports, each entitled "Operation and Maintenance of the LASA, Monthly Progress Report" were distributed for each month in which a quarterly technical report was not required. Five quarterly technical reports plus this final which includes the final four month period were published and distributed. Their report numbers (both originator and DDC) and dates are:

(1) T/R 2056-72-16 (AD 742 488) 15 Mar 72

(2) T/R 2056-72-21 (AD 745 753) 15 Jun 72

(3) T/R 2056-72-24 (AD 752 601) 15 Sep 72

(4) T/R 2056-72-28 (AD 757 276) 15 Dec 72

(5) T/R 2056-73-33 (AD 759 531) 15 Mar 73

Five technical reports which are identified in the above reports plus other technical letters were submitted to the VSC project officer.

### 8.2 Operations Data

Operations data distributed from the LDC included:

(1) "Defective Signal Channel Status Report", 83 weekly.

(2) "Data Interruption Log", 83 weekly issues.

(3) "Develocorder Operations Log", 83 weekly issues.

(4) "LASA Regional/Near-regional Detection Bulletin" 17 issues since 14 Feb 73.

(5) "Array Status Report", three issues.

(6) "Array Modification Status Report", one issue.

The above data reports were distributed to selected using agencies as approved by the VSC Project Officer.

### 8.3 Alternate Management Summary Reports

Alternate Management Summary Reports (AMSR) were

prepared and distributed from the Philco-Ford Communications System Division headquarters for each month of the contract period.

## REFERENCES


1. Philco-Ford Corp. Montana LASA Second Quarterly Technical Report, ESD-TR-68-428 (AD 846 155) Billings, MT., Nov 68.

2. Philco-Ford Corp. Montana LASA Final Technical Report, Project VT/1708, T/R 2039-71-13 (AD 738 003) Billings, MT., 22 Dec 71.

3. Philco-Ford Corp. "Montana LASA Array Status Report" Issue AS-67, 1 May 72.

4. Philco-Ford Corp. Montana LASA Third Quarterly Technical Report, ESD-TR-69-57 (AD 850 373) Billings, MT., Feb 69.

5. Philco-Ford Corp. Montana LASA Annual Report A-001-30. Billings, MT., 31 May 68.

6. Philco-Ford Corp. Montana LASA Fourth Quarterly Technical Report, Project VT/2708, T/R 2056-72-28 (AD 757 276) Billings, MT., 15 Dec 72.

7. Davies, D. Seismic Discrimination, ESD-TR-71-191, MIT Lincoln Laboratory Semiannual Technical Summary, 30 Jun 71, pp 43-44.

8. Philco-Ford Corp. Montana LASA Second Quarterly Technical Report, Project VT/2708, T/R 2056-72-21 (AD 745 753) Billings, MT., 15 Jun 72.

9. Philco-Ford Corp. Montana LASA Third Quarterly Technical Report, Project VT/2708, T/R 2056-72-24 (AD 752 601) Billings, MT., 15 Sep 72.

10. Philco-Ford Corp. Montana LASA Second Quarterly Technical Report, Project VT/1708, T/R 2039-71-07 (AD 885 649) Billings, MT., 15 Jun 71.

11. Philco-Ford Corp. Montana LASA First Quarterly Technical Report, Project VT/2708, T/R 2056-72-16 (AD 742 488) Billings, MT., 15 Mar 72.

12. Philco-Ford Corp. "Montana LASA Array Modification Status Report" Issue MS-52, 12 Dec 72.